Appendix F1 – Assessment of Controls (Watershed Restoration Assessment)

WHEEL CREEK
WATER CHEMISTRY MONITORING
YEAR 9 REPORT

Prepared for:

Harford County
Department of Public Works
Watershed Protection and Restoration
212 South Bond Street
Bel Air, Maryland 21014

Prepared by

Thomas S. Jones, Jr.
Brent Hood
Ryan Corbin
Versar, Inc.
9200 Rumsey Road, Suite 1
Columbia, Maryland 21045

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1.0 INTRODUCTION

Harford County received Chesapeake and Atlantic Coastal Bays 2010 Trust Fund grants to address impacts to Wheel Creek through stream restoration, stormwater BMP retrofits, public outreach, and physical, biological, and water chemistry monitoring. Additionally, through mutual agreement with Maryland Department of the Environment (MDE), Wheel Creek has been identified as the County's priority watershed to satisfy National Pollutant Discharge Elimination System (NPDES) Municipal Separate Storm Sewer System (MS4) monitoring requirements.

Wheel Creek watershed drains 435 acres consisting of high density residential and commercial land uses in the headwaters, and medium and low density residential and forest land uses in the remainder. The stream has been altered by changes in hydrology in the watershed associated with recent urbanization and historical agricultural land use. Imperviousness has increased to 27% in the past three decades of development (Harford County DPW 2008).

Harford County contracted with Versar, Inc., to conduct stormwater runoff monitoring in Wheel Creek to comply, in part, with both the monitoring requirement of the MS4 permit and the monitoring requirements associated with the Chesapeake and Atlantic Coastal Bays 2010 Trust Fund stream restoration initiative. Baseflow monitoring was completed by Versar, Inc., and long-term flow monitoring, coincident with this monitoring effort at all three of the water chemistry monitoring stations, was conducted by Versar, Inc. from June 2016 to the present. Maryland DNR has conducted biological and physical monitoring each spring and summer since 2009. Geomorphological assessments have been conducted annually since 2010, first by the County and subsequently by Versar. United States Geological Survey (USGS) operates a stream flow gauging station near the mouth of Wheel Creek (USGS Station 0158175320) and a stage level gauging station and tipping bucket rain gauge in Atkisson Reservoir (USGS Station 01581753).

This report documents the water chemistry monitoring activities undertaken by Harford County, Versar, and USGS, and summarizes the data obtained from July 1, 2018 to June 30, 2019. The activities included capturing eight wet weather events and monthly baseflow monitoring in the Wheel Creek watershed.

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2.0 STUDY AREA AND STUDY DESIGN

Wheel Creek forms a portion of the Atkisson Reservoir Watershed and resides within the Bush River Basin. It consists of approximately 435 acres of watershed, 2.2 linear stream miles, and five stormwater management facilities. Four stream reaches were targeted for restoration and four stormwater facility retrofits were planned in the drainage area (Harford County DPW 2008). Restoration and retrofit activities began in 2012 and continued through April 2017 (Table 2-1). Pre-construction and post-construction data will be used to assess performance of a portion of the stream restoration and stormwater BMP retrofit projects. The current monitoring period represents the second full year of post-restoration data collection and analyses.

Table 2-1. Timeline of restoration and retrofit projects in Wheel Creek watershed (M. Dobson pers. comm.)

Construction Projects	Start Date	Completion Date
Gardens of Bel Air (Pond A)	September 8, 2012	December 20, 2012
Calverts Walk (UMS-1)	January 14, 2013	April 4, 2013
Festival of Bel Air (Pond C)	May 12, 2015	August 7, 2015
Country Walk 1A (Pond D)	September 21, 2015	December 11, 2015
MMS-5, MB-4, MB-1	December 7, 2015	February 26, 2016
Water Quality Facilities (4)	December 7, 2015	March 18, 2016
Lower Wheel Creek	September 19, 2016	March 2017
Country Walk 1B (Pond E)	December 2016	April 2017

The water chemistry monitoring study design employs before and after conditions assessments corresponding to comparisons of pre- and post-restoration and retrofit phases. The initiation, termination, and duration of the phases vary by station and the schedule of restoration construction.

Three long-term automated water chemistry sampling and flow logging stations were established at Stations WC002, WC003, and WC004 (Figure 2-1). Station WC004 is located on the middle branch, immediately downstream of the stormwater retrofit at Festival Shopping Center (Point C). Stations WC003 and WC004 bracket completed stormwater retrofits at Pond D and Pond E along the middle branch. Station WC002 is located on the mainstem and water chemistry data collected there will provide an overall assessment of the benefits of retrofit and restoration projects in upstream tributaries (Figure 2-2). Baseflow monitoring took place at three stations along the Wheel Creek main stem and tributaries (WC002, WC003, and WC004).

Figure 2-1. Wheel Creek Watershed long-term water chemistry monitoring stations

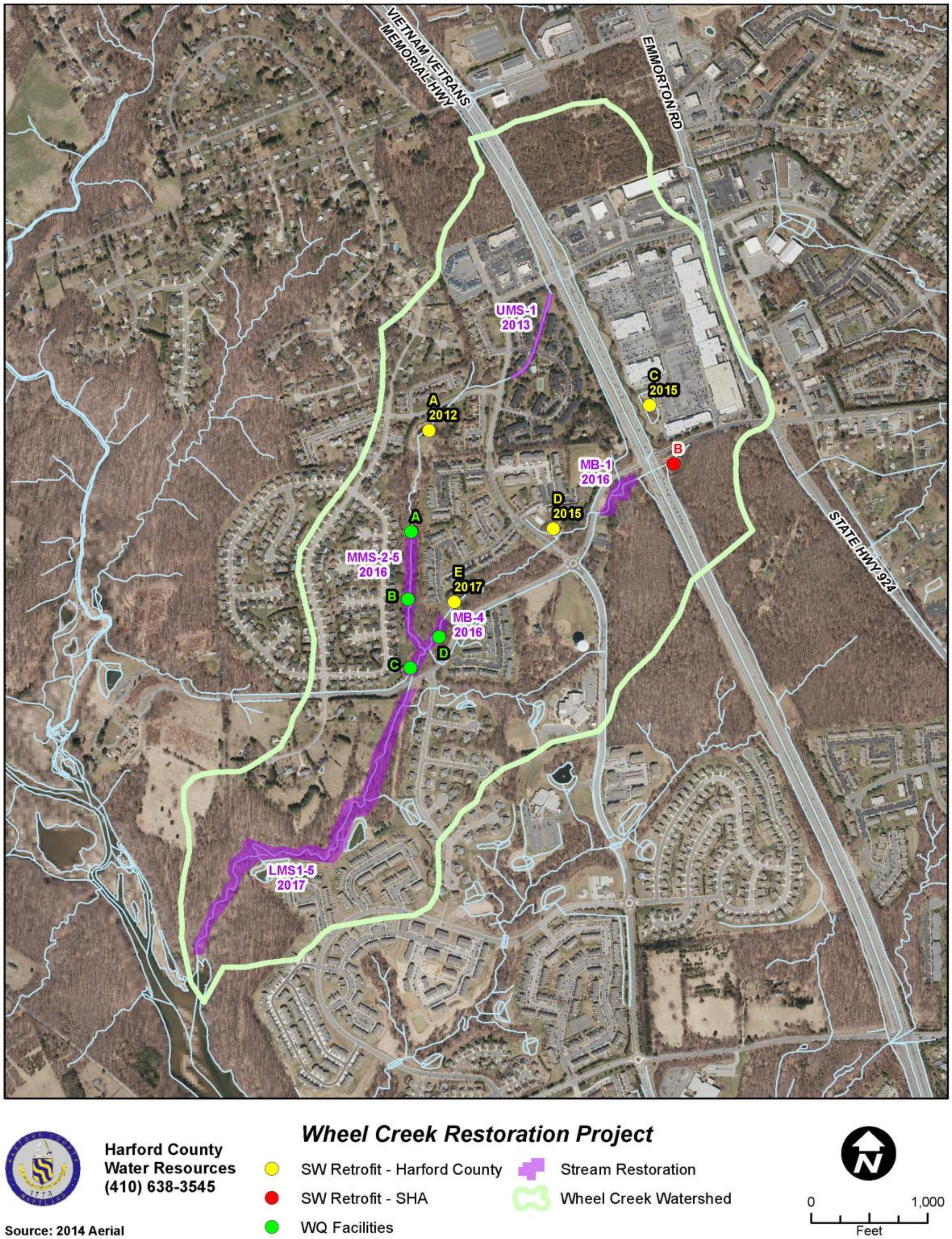

Figure 2-2. Stream restoration and stormwater retrofit sites in Wheel Creek watershed.

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3.0 METHODS AND MATERIALS

3.1 STORMFLOW MONITORING

Fixed, automated stormflow monitoring and long-term flow logging stations were situated at the following locations:

- WC002 – Wheel Creek mainstem at Wheel Road
- WC003 – Middle branch at Cinnabar Lane
- WC004 – Middle branch off Wheel Court

Stormflow samples were collected by Versar staff using American Sigma 900Max samplers at Stations WC002, WC003, and WC004 working in conjunction with ISCO 4230 bubbler flow meters. Automated sampling equipment was installed in September 2010 at Station WC002 and Station WC003 and mid-October 2010 at Station WC004. During storms, bubbler flow meter tubing and carriers were secured at the downstream end of culverts at Station WC002 and Station WC003 while the bubbler tube at Station WC004 was secured instream. Automated samplers contained 24, one-liter polypropylene bottles and were programmed to start at a specific time (based on the storm forecast) by field staff to sample the rising, peak, and falling limbs of the storm on a time-paced basis. Separate composite samples were created on a discharge volume-proportional basis to represent the rising, peak, and falling limbs of the stream hydrograph.

Eight events were monitored between July 1, 2018 and June 30, 2019 (Table 3-1). Event rainfall duration was calculated from the first to the last measurable amounts of rain that triggered the tipping mechanism within the rain gauge. Antecedent dry time was calculated by determining the time interval between the initiation of rainfall for the monitored event and the cessation of rainfall for the prior event. Qualifying storm events required a minimum of 24 hours where there had been less than 0.03 inches total accumulated rainfall.

Flow rate during monitored storm events was determined using Manning's equations specific to each outfall pipe at Stations WC002 and WC003 and by rating curve at Station WC004.

The rating curve at Station WC004 was prepared using directly-measured velocities, over a range of stages, along a stream channel cross-section (Appendix B). Versar field staff measured velocity and channel depth using a Marsh-McBirney Flowmate 2000 flowmeter, with sensor attached to a graduated wading rod (Jones and Hage 2011). Automated storm sampling procedures are described in fuller detail in the project's Quality Assurance and Quality Control Document (Jones and Hage 2011).

Stream water samples were tested for the analytes listed in Table 3-2. Since May 2013, samples were tested for an expanded suite of analytes that included: turbidity, chloride, dissolved total Kjeldahl nitrogen (TKN), dissolved nitrate plus nitrite, and dissolved total phosphorus. Analyses of dissolved constituents, along with nitrate, were discontinued after the July 17, 2018 storm. Analytes with multiple detection limits are presented as a range in Table 3-2.

Table 3-1. Statistics for monitored storms, July 2018 – June 2019

Date	Rainfall Total (in.)	Rainfall Duration (hr.)	Antecedent Dry Time (hr.)
17-Jul-18	1.78	3.83	48.00
17-Sep-18	2.52	26.30	92.37
26-Oct-18	1.30	25.53	133.65
15-Nov-18	1.16	11.35	57.22
4-Jan-19	0.32	17.28	88.15
20-Feb-19	0.15	3.08	75.92
10-Jun-19	0.48	25.00	83.25
12-Jun-19	0.58	9.25	44.00

Rainfall recorded by primary onsite rain gauge at Station WC002

Table 3-2. Parameters, methods, detection limits, and water quality criteria for Wheel Creek monitoring

Parameter	Analytical Method	Reporting Limit (mg/L)	Method Detection Limit (mg/L)	Wheel Creek Storm and Baseflow	MD Freshwater Criteria[(a)] Acute (µg/l)	MD Freshwater Criteria[(a)] Chronic (µg/l)	EPA Recom-mended Ambient Water Quality Criteria[(b)] (mg/L)
BOD-5	SM 5210 B	1-2	2	√			
Nitrate[(e)]	EPA 300.0	0.1	0.04	√			
Nitrate + Nitrite	EPA 300.0	0.1-0.2	0.04	√			0.69 (Total N)[(c)]
Total Kjeldahl Nitrogen	EPA 351.2	0.5-1	0.5	√			
Orthophosphate	SM 4500-P E	0.01-0.1	0.003	√			
Total Suspended Solids	SM 2540D	2-60	4-20	√			
Copper	EPA 200.7	0.002-0.04	0.0002-0.0099	√	13	9	
Lead	EPA 200.7 EPA 200.8	0.001-0.005	0.00006-.005	√	65	2.5	
Zinc	EPA 200.7	0.01-0.02	0.002-0.0062	√	120	120	
Chloride[(d)]	EPA 300.0	2-50	0.17-50	√			860 (acute) 230 (chronic)
Ammonia	SM 4500 NH3G	0.1-0.3	0.05	√			
Total Phosphorus	EPA 365.4	0.1	0.05	√			0.03656
Hardness	SM234B	0.7-50	0.06-50	√			
Turbidity	SM2130B	0.01-5	0.14-0.7	√			
Dissolved Nitrate + Nitrite[(e)]	EPA 300.0	0.1	0.04	√			
Dissolved Total Kjeldahl Nitrogen[(e)]	EPA 351.2	1.2-2.5	0.6-1.3	√			
Total Petroleum Hydrocarbons	EPA 1664B	5	1.4-5	√			
E. coli (reported as MPN/100 ml)	SM 9223B	1	0-1.0	√			

(a) Values from COMAR 26.08.02.03-2 (undated).
(b) U.S. EPA 2000. Recommended criteria are derived from the 25th percentile of concentrations in all streams in the ecoregion.
(c) Total nitrogen concentration is the sum of total Kjeldahl nitrogen and combined nitrate plus nitrite.
(d) U.S. EPA 1988. Ambient Water Quality Criteria for Chloride.
(e) Tested only during the July 17, 2018 storm.

Storm event mean concentrations (EMCs) were calculated individually for each storm by obtaining the concentration of each pollutant, weighted according to limb discharge volume. Limb discharges were determined by plotting the portion of the storm hydrograph represented by the composite sample and integrating under the curve using Flowlink software. For TPH and *E. coli*, which were collected by grab during irregular occasions during stormflow, a simple average concentration without flow weighting was calculated ("greater than" *E. coli* results were set to the numerical result).

Estimated pollutant loading values for each storm were determined by multiplying the storm EMCs by the total storm discharge in cubic feet. Total storm discharge was determined by plotting the storm hydrograph and integrating under the curve using Flowlink software.

3.2 BASEFLOW MONITORING

Baseflow monitoring was completed monthly by Versar staff. Grab samples were collected at the locations listed below.

- WC002 – Wheel Creek mainstem at Wheel Road
- WC003 – Middle branch at Cinnabar Lane
- WC004 – Middle branch off Wheel Court

3.3 LONG-TERM FLOW RATE LOGGING

Long-term flow rate logging was conducted at Stations WC002, WC003, and WC004 described above. Maryland Department of Natural Resources (DNR) installed Solinst flow loggers in 2012 and maintained them through June 2016, at which point Versar assumed responsibility for monitoring and maintenance. Versar conducted monthly site inspections, logger downloads, and baseflow discharge measurements between July 2018 and June 2019. Storm discharge measurements were also collected whenever possible to verify the rating curve at each station.

During the winter months, the Solinst flow loggers were removed from service to prevent damage to the sensors due to icing. During these periods, ISCO 4230 bubbler flow meters were installed to capture level data while the Solinst loggers were offline.

Complete flow series for each station were compiled from the Solinst and ISCO logger data. Staff performed quality control on the level time series to remove any anomalous data (e.g., resulting from manipulation during Solinst data offloads). Levels were corrected to reflect observed staff gauge readings, and linear drift corrections were applied to the time series at each station to compensate for logger drift. A rating curve was established at each of the three logging stations to convert each logger's level data to flow rate (Appendix B).

3.4 RAINFALL LOGGING

Rainfall was recorded by an Onset HOBO electronic, tipping-bucket rain gauge situated in an open area near Station WC002. The gauge was downloaded and maintained by Versar field staff and is the primary gauge used for storm event rainfall totals. Daily rainfall recorded by the gauge is presented in Appendix C. Rainfall records from USGS' Atkisson Reservoir gauge (0.8 miles away to the SW), the secondary rainfall recorder, were used to supplement the onsite data in cases where onsite gauge data were unavailable due to power interruptions or mechanical failures.

3.5 DETERMINATION OF STORM EVENT POLLUTANT LOADS

Pollutant loads were determined by multiplying the pollutant event mean concentration (a stream flow volume-weighted mean of analytical results from laboratory analysis) by the total storm discharge at the point of sample collection. Stream discharge volume for a specific time interval (for a specific limb or the total event) is determined by integrating under the flow rate hydrograph over the time period of interest. The pollutant event mean concentration (EMC) for a given storm is determined by:

$$\text{EMC} = \frac{\sum_{i=1}^{3} C_i V_i}{\sum_{i=1}^{3} V_i}$$

Where:

EMC = Event Mean Concentration of specific pollutant

i = Numerical representation of storm limb (1=rising, 2=peak, 3=falling)

C_i = Pollutant concentration at limb i

V_i = Corresponding discharge represented by composite sample collected for limb i.

The average pollutant EMC for the monitoring year is an arithmetic mean of individual storm EMCs.

Pollutant load for a given storm is calculated by:

$$L = (k_1 / k_2) \times (\text{EMC} \times V_T)$$

Where:

L = estimated load in pounds
k_1 = conversion factor 28.317 liters per cubic foot
k_2 = conversion factor of 453,592.4 milligrams per pound
V_T = estimated total storm runoff in stream in ft^3

The average pollutant load for the monitoring year is an arithmetic mean of individual storm loads.

3.6 DETERMINATION OF AVERAGE ANNUAL AND SEASONAL EMC AND TOTAL ANNUAL AND SEASONAL LOAD

Average annual storm EMCs for each pollutant at each station were determined by obtaining the arithmetic mean of individual storm EMC data for a given year. Average annual baseflow Mean Concentrations (MCs) were developed by calculating the arithmetic mean of concentration data. Average seasonal EMCs and MCs were obtained by using the same method, except on a seasonal basis. Below-reportable detection limit results were set to zero when determining average EMCs and determining baseflow MCs.

Total annual load was determined by (a) multiplying all stormflow volume in a given year at a given station by the corresponding average annual EMC for each pollutant, (b) multiplying all baseflow volume in the same year by the corresponding average annual MC, and (c) summing the result.

3.7 SUSPENDED SEDIMENT TRANSPORT MONITORING

Suspended sediment transport was monitored at all three Wheel Creek storm monitoring stations, WC002, WC003, and WC004 (Figure 2-1). Sediment samples were collected in conjunction with wet weather samples from July 2018 through June 2019. Suspended sediment was monitored during eight wet weather sampling events using a modified siphon sampler (Diehl 2008) outfitted with a HOBO® U20 depth logger for continuous stage recording. The modified siphon sampler was developed by USGS to sample shallow water at closely spaced vertical intervals, enabling samples to be collected passively at multiple stages of the rising limb of the hydrograph. Each sampler included six 1000-mL sample containers oriented horizontally with an intake tube and an air vent, which allowed sample collection at up to six two-inch incremental stages. Samples collected were analyzed individually for suspended sediments following a standard method for total suspended solids (SM2540D; APHA 1999), with filtration of the full 1000-mL sample.

Since the sampler devices could not be deployed in the same location as the gauge recorders without causing interference, discharge corresponding to each sample was determined using depth data obtained from the HOBO® loggers. The loggers were set to record pressure and temperature data at 1-minute intervals for the full duration of their deployment. The logger data were then post-processed using HOBOware Pro 2.7.3 software, to correct for changes in barometric pressure. The resulting data were used to determine the approximate time that each sample bottle was filled, and the corresponding discharge from the time of sample collection was obtained from the storm event flow rate graphs for each station. The relationship between discharge and suspended sediment concentration was then plotted to create a sediment-transport curve (Glysson 1987) for each station.

3.8 STATISTICAL TEST FOR TREND

A Kendall's Tau-b statistical test (Kendall 1948) was performed on the compiled baseflow concentration and individual storm EMC data at the monitoring stations. This test is a non-parametric test that compares the ranks of parameter concentrations to the ranked collection dates. The test was used to determine whether a significant upward or downward trend in concentration occurred over time.

3.9 COMPARISON OF PRE- TO POST-RESTORATION DATA

The assessment of the effectiveness of restoration projects in Wheel Creek relies upon comparisons of pre-restoration conditions to post-restoration conditions. Because the implementation of restoration projects in the watershed was staggered, the effectiveness of groups of the projects was determined strategically using the location of the applicable monitoring station and construction timelines. The time periods for the pre-restoration and post-restoration conditions were appropriately defined at each station, so that the during-construction phases were eliminated from the comparisons. Note the following:

- Pre-restoration and post-restoration conditions evaluated using data from Station WC004 were governed only by the construction of Pond C at Festival of Bel Air,
- Pre-restoration phase for data collected at Station WC002 was governed by the earliest construction of projects on the mainstem (i.e., Pond A in September 2012),
- Pre-restoration phase for data collected at Station WC003 was governed by the start of construction at Pond C in May 2015 (same as at Station WC004) but was set to the same timeframe as Station WC002 for consistency, and
- Post-restoration phase at both Station WC002 and Station WC003 was set to the conclusion of construction of Pond E at Country Walk 1B in April 2017 since the effort was upstream of both stations.

The relationship between restoration construction schedule, which monitoring station data are used in efficiency evaluations, and the type of evaluations are provided in Table 3-3.

Comparisons were conducted in two ways: a) total annual load for fiscal years 2017-2019 (post-restoration) to 2010-2011 (pre-restoration); and b) post-restoration storm EMCs and baseflow MCs to pre-restoration storm EMCs and baseflow MCs.

3.9.1 Comparison of Ratios Between Stations WC002 and WC003

Because only one monitoring station is located on the mainstem, the assessment of the effectiveness of restoration projects in improving water quality in the mainstem, as well as projects on the middle branch located between Station WC002 and Station WC003 (e.g., MB-4 and one water quality facility), was isolated and performed indirectly by comparing ratios of pollutant loads and concentrations between the stations during the pre-restoration and post-restoration phases. The ratio (or relationship) of pollutant levels between the two stations during the pre-restoration period was taken as a baseline; a lowering of the ratio during the post-restoration period would indicate pollutant reduction between the stations.

The ratio of total load between the downstream station and the upstream station was calculated for the following pollutants: total nitrogen, total phosphorus, total suspended solids (TSS), ammonia, BOD, copper, lead, and zinc.

For this method, total loads were calculated using data from the pre-restoration period (2010-2011) and post-restoration period (FY 2017-2019) and then compared to one another. The ratio between stations is calculated from the following equation:

$$\text{Ratio} = (1 - (L_3/L_2)) * 100$$

Where:

L_3 = Load at Station WC003 (upstream)
L_2 = Load at Station WC002 (downstream)

To determine restoration effectiveness in terms of storm EMC and baseflow MC, the ratio between the average EMC or MC at the downstream Station WC002 and the upstream Station WC003 was calculated for the pre-restoration time period and the post-restoration time period. The ratios of average concentrations between the downstream station and the upstream station, during both periods, were compared for each analyte. The ratio between stations is calculated from the following equation:

$$\text{Ratio} = (1 - (C_3/C_2)) * 100$$

Where:

C_3 = Concentration at Station WC003 (upstream)
C_2 = Concentration at Station WC002 (downstream)

A paired Student's t test was used to determine significance of the difference in EMC or MC between the stations.

3.9.2 Comparison of Pre- and Post-Restoration Conditions at all Stations

Calculations of absolute pollutant removal efficiencies were used to characterize the aggregated effectiveness of restoration projects located within each station's subwatershed. Both storm EMC and baseflow MC data accumulated during the pre-restoration and post-restoration phases at each station, defined above, were compared. The efficiencies were calculated using the same percentage equation defined in Section 1.2.1. A Student's t test was used to determine significance.

Table 3-3. Restoration construction schedule, applicable monitoring stations, and recommended efficiency evaluation methods

Construction Projects	Reach	Start Date	Completion Date	No. Storms		No. Baseflows		Efficiency Evaluation
				Pre-restoration	Post-restoration	Pre-restoration	Post-restoration	
Gardens of Bel Air (Pond A)	Mainstem	September 8, 2012	December 20, 2012	17 (WC002) 18 (WC003)	25 (WC002) 24 (WC003)	33 (WC002) 32 (WC003)	38 (WC002) 38 (WC003)	Compare differences between WC002 & WC003 during pre- and post-conditions
Calverts Walk (UMS-1)	Mainstem	January 14, 2013	April 4, 2013					
MMS-5, MB-4	Mainstem, Middle Branch	December 7, 2015	February 26, 2016					
Water Quality Facilities (4)	Mainstem (3), Middle Branch (1)	December 7, 2015	March 18, 2016					
Festival of Bel Air (Pond C)	Middle Branch	May 12, 2015	August 7, 2015	42	34	52	45	WC004 before & after
Country Walk 1A (Pond D)	Middle Branch	September 21, 2015	December 11, 2015	17 (WC002) 18 (WC003)	18 (WC002) 19 (WC003)	33 (WC002) 32 (WC003)	24 (WC002) 24 (WC003)	WC002 before & after; WC003 before & after
MB-1	Middle Branch	December 7, 2015	February 26, 2016					
Country Walk 1B (Pond E)	Middle Branch	December 2016	April 2017					

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4.0 RESULTS AND DISCUSSION

Results of stormflow and baseflow sampling performed from July 1, 2018 through June 30, 2019 are presented and discussed in this section. The individual sample analytical data are compiled into tables while annual average concentrations and loadings are presented in tabular and graphical form.

4.1 STORMFLOW CONCENTRATION RESULTS

Analytical results for storm samples collected at each of the three stations are presented in Table 4-1. Total nitrogen results were greater than the EPA recommended reference value of 0.69 mg/L (U.S. EPA 2000) in 97.1% of the samples in this monitoring period. Of the samples in which total phosphorus was detected, 86.2% of the results were greater than the EPA recommended reference value of 0.03656 mg/L. Orthophosphate was detected in 33.3% of stormflow samples collected. Ammonia results were above the detection limit in 37.7% of stormflow samples collected at all stations during the year. Ammonia concentrations were highest during the January storm event. BOD was detected in 85.5% of samples, with concentrations exceeding 5 mg/L during the July 18, 2018 storm at all three stations.

Zinc continued to be detected in 100% of stormflow samples collected during the monitoring period. The zinc concentration was greater than MDE's acute criterion for surface water in only two (2.9%) of the samples (Table 3-2).[1] Zinc concentrations were highest during the July storm event. Lead concentrations were above the detection limit in 27.5% of the samples, none of which were above the MDE acute criterion. Copper concentrations were above the detection limit in 72.5% of samples; however, only 8.7% were greater than the MDE acute criterion for surface water.

E. coli concentrations were equal to or greater than the maximum reportable result (2,420 MPN/100ml) in 33.3% of stormflow grab samples and were generally highest at Station WC002. TPH was not detected in any of the 24 stormflow grab samples collected at the monitoring stations. Hardness was generally the lowest at Station WC004. Turbidity was generally highest at Station WC003, probably due to the additive effects of suspended matter transported from the stormwater collection pond just upstream of this station. TSS was above the detection limit in 98.6% of samples, with highest concentrations also at Station WC003. Chloride was ubiquitous in storm runoff samples, with 10.1% of the results falling above the acute criterion established by USEPA. Chloride concentrations exceeded 880 mg/L during the rising and peak limbs at all three stations during the February 20-21, 2019 storm and was elevated during the November storm, probably because of flushing of deicing compound applied on road surfaces.

Storm sample analytical results for filtered samples are presented in Table 4-2. Due to a change in the analytical laboratory, only the July 2018 storm had filtered sample results. TKN

[1] The zinc, lead, and copper criteria are based on the dissolved form, while the laboratory analytical results are for total metal concentration. Comparisons to surface water criteria are for discussion purposes only and do not imply violations of surface water standards.

was detected in 77.8% of these filtered samples, while nitrate plus nitrite was detected in 100% of filtered samples taken at all three stations. Total nitrogen results were comparable to unfiltered samples in that they were greater than the EPA recommended reference value of 0.69 mg/L in 88.9% of samples. Phosphorus was not detected in any of the filtered samples at all three stations.

4.2 BASEFLOW CONCENTRATION RESULTS

Baseflow sample analytical results are presented in Table 4-3. Under baseflow conditions, concentration values for total phosphorus were above the detection limit in 20% of samples. Orthophosphate was detected in 33.3% of baseflow samples. Ammonia was detected in 30.0% of samples, mostly at Station WC002, and TSS was detected in 73.3% of baseflow samples. Total nitrogen was above the detection limit in all the baseflow samples and all concentration levels were greater than the EPA reference value (0.69 mg/L). Total nitrogen concentrations tended to be lowest at Station WC003.

Zinc was detected in all baseflow samples and generally at the highest concentrations at Station WC003. Lead and copper were detected in 13.3% and 76.7%, respectively, of baseflow samples. All concentrations of all metals were lower than MDE's applicable chronic surface water criteria.

BOD was detected in 33.3% of samples. Maximum BOD concentrations at Stations WC002 and WC003 were recorded for the December baseflow monitoring event. Baseflow concentrations of combined nitrate plus nitrite were generally higher at Station WC004 than at the other stations. Turbidity was generally lowest in baseflow samples taken from Station WC004 and highest in baseflow samples taken from Station WC003.

Chloride concentrations were elevated January to February for all stations. Generally, chloride was highest at Station WC004 for a given baseflow sampling event and became gradually lower when progressing downstream to Station WC002. The maximum observed chloride concentrations for Stations WC003 and WC004 occurred during the February sampling event and January sampling event, respectively. The lowest chloride concentrations occurred during the December sampling event at all stations.

Hardness, a characteristic of surface waters, was quantified in all baseflow samples. Concentrations greater than 120 mg/L are considered "Hard", while concentrations exceeding 180 mg/L are considered "Very Hard". All baseflow samples collected contained Very Hard water, and the highest hardness values were found at Station WC004.

E. coli bacteria concentrations were detected in all baseflow samples, when tested, at all stations, ranging in concentration from 6.3 to greater than 2,420 MPN/100ml. The maximum concentrations for Stations WC002 and WC003 during the monitoring period occurred during the December sampling event, and the maximum concentration for Station WC004 occurred during the June sampling event. In general, *E. coli* concentrations were highest during the warmer months and lowest during the colder months.

Table 4-1. Stormflow water chemistry results, July 2018 – June 2019. All concentrations are in units of mg/L unless indicated.

Storm Date	Limb	Dis-charge (cf)	5-Day BOD	Ammo-nia	Nitrate	Nitrate + Nitrite	Ortho-phos-phate	TKN	Total P	TSS	Copper (µg/l)	Lead (µg/l)	Zinc (µg/l)	TPH	*E. coli* (MPN/ 100 ml)	Total Nitro-gen	Hard-ness	Chlor-ide	Turbid-ity (NTU)
Station WC002																			
7/17/2018	Rising	40,713	8.79	0.13	1.1	1.1	0.011	2.1	0.33	214	18.6	4.1	110	<5	>2420	3.2	99.7	79.2	85
7/17/2018	Peak	143,606	6.42	0.15	0.76	0.72	0.021	1.5	0.22	148	12.1	2.6	45.9	N.C.	N.C.	2.22	32	26.5	65
7/17/2018	Falling	66,217	5.71	0.094	0.6	0.58	0.019	0.82	0.069	45	<40	<3	22	N.C.	N.C.	1.4	31.9	30.2	9.4
9/17/2018	Rising	62,066	3	<0.3	N.A.	0.6	<0.1	0.7	<0.1	20	7	0.8	33	N.C.	N.C.	1.3	67	59.9	13.3
9/17/2018	Peak	875,729	4	<0.3	N.A.	0.5	<0.1	1.2	0.2	101	16	3	40	<5	>2420	1.7	34	15.4	55.7
9/17/2018	Falling	158,871	2	<0.3	N.A.	0.5	<0.1	0.9	0.1	22	7	<1	19	N.C.	N.C.	1.4	34	21.1	22.1
10/26/2018	Rising	53,604	4	<0.3	N.A.	1	<0.1	1.1	0.12	51	9	2	76	<5	186	2.1	115	94.3	7.37
10/26/2018	Peak	177,484	3	<0.3	N.A.	0.4	<0.1	0.8	0.1	26	8	1	80	N.C.	N.C.	1.2	50	34	6.23
10/26/2018	Falling	20,515	1	<0.3	N.A.	0.8	<0.1	0.6	<0.1	2	6	<1	42	N.C.	N.C.	1.4	70	54	4.22
11/15/2018	Rising	26,946	1	0.3	N.A.	1.1	<0.1	0.6	<0.1	8	4	<1	42	N.C.	N.C.	1.7	148	671	6.6
11/15/2018	Peak	89,757	3	<0.3	N.A.	0.4	<0.1	0.8	<0.1	13	6	<1	56	N.C.	N.C.	1.2	110	791	12.5
11/15/2018	Falling	7,614	1	<0.3	N.A.	0.7	<0.1	<0.5	<0.1	5	<2	<1	33	<5	2420	0.7	70	122	5.9
1/4/2019	Rising	16,005	1	0.3	N.A.	1.7	<0.1	<0.5	<0.1	1	<2	<1	17	N.C.	N.C.	1.7	134	107	2.45
1/4/2019	Peak	30,660	1	<0.3	N.A.	0.8	<0.1	0.6	<0.1	12	18	<1	22	N.C.	N.C.	1.4	67	61.6	9.05
1/4/2019	Falling	19,402	1	<0.3	N.A.	1.1	<0.1	<0.5	<0.1	1	2	<1	14	<5	4.1	1.1	96	77.3	3.8
2/20/2019	Rising	9,370	<1	<0.3	N.A.	1.7	<0.1	<0.5	<0.1	4	<2	<1	25	N.C.	N.C.	1.7	180	1,080	2.51
2/20/2019	Peak	18,029	<1	<0.3	N.A.	1	<0.1	0.6	<0.1	8	3	<5	38	N.C.	N.C.	1.6	178	1,750	8.99
2/20/2019	Falling	13,955	<1	<0.3	N.A.	1	<0.1	<0.5	<0.1	3	<2	<1	31	<5	37.9	1	158	970	4.51
6/10/2019	Rising	11,988	<1	0.16	N.A.	1.4	0.02	<0.5	0.02	<1	<2	<1	12	N.C.	N.C.	1.4	152	122	2.55
6/10/2019	Peak	35,352	2	0.09	N.A.	0.6	0.07	0.7	0.05	13	<2	<1	23	N.C.	N.C.	1.3	95	51.4	6.88
6/10/2019	Falling	8,950	<1	0.06	N.A.	1	0.04	0.6	0.02	2	<2	<1	12	<5	687	1.6	122	78.9	3.37
6/12/2019	Rising	S.M.	S.M.	S.M.	S.M.	S.M.	S.M.	S.M.	S.M.	S.M.	S.M.	S.M.	S.M.	N.C.	N.C.	S.M.	S.M.	S.M.	S.M.
6/12/2019	Peak	S.M.	S.M.	S.M.	S.M.	S.M.	S.M.	S.M.	S.M.	S.M.	S.M.	S.M.	S.M.	N.C.	N.C.	S.M.	S.M.	S.M.	S.M.
6/12/2019	Falling	S.M.	S.M.	S.M.	S.M.	S.M.	S.M.	S.M.	S.M.	S.M.	S.M.	S.M.	S.M.	<5	>2420	S.M.	S.M.	S.M.	S.M.

S.M. = Sampler Malfunction
N.C. = Sample Not Collected
N.A. = Parameter Not Analyzed

Table 4-1. (Continued)

Storm Date	Limb	Dis-charge (cf)	5-Day BOD	Ammo-nia	Nitrate	Nitrate + Nitrite	Ortho-phos-phate	TKN	Total P	TSS	Copper (µg/l)	Lead (µg/l)	Zinc (µg/l)	TPH	*E. coli* (MPN/ 100 ml)	Total Nitro-gen	Hard-ness	Chlor-ide	Turbid-ity (NTU)
Station WC003																			
7/17/2018	Rising	10,847	9.15	0.22	1.1	1.2	0.012	3.5	0.71	344	36.1	9.7	164	<5	>2420	4.7	115	95.8	150
7/17/2018	Peak	30,535	5.94	0.16	0.8	0.76	0.016	1.4	0.18	115	14.4	2.9	49.1	N.C.	N.C.	2.16	42.3	37	65
7/17/2018	Falling	12,851	5.14	0.1	0.61	0.58	0.012	0.91	0.071	59	<40	1.3	27.7	N.C.	N.C.	1.49	47.5	50.1	19
9/17/2018	Rising	32,970	2	<0.3	N.A.	0.4	<0.1	0.8	<0.1	13	8	0.6	18	N.C.	N.C.	1.2	90	71.9	8.5
9/17/2018	Peak	173,676	2	<0.3	N.A.	0.4	<0.1	0.9	<0.1	30	10	1	21	<5	>2420	1.3	36	24.2	15.7
9/17/2018	Falling	27,137	1	<0.3	N.A.	0.5	<0.1	0.6	<0.1	7	7	<1	14	N.C.	N.C.	1.1	62	49.7	11.6
10/26/2018	Rising	10,599	5	<0.3	N.A.	0.6	<0.1	1.3	0.18	65	13	3	95	<5	166	1.9	120	118	11.9
10/26/2018	Peak	56,268	2	<0.3	N.A.	0.4	<0.1	0.9	<0.1	18	7	<1	40	N.C.	N.C.	1.3	50	50.6	6.62
10/26/2018	Falling	10,478	1	<0.3	N.A.	0.5	<0.1	0.5	<0.1	5	5	<1	18	N.C.	N.C.	1	70	63.5	4.61
11/15/2018	Rising	5,873	1	<0.3	N.A.	0.8	<0.1	0.6	<0.1	15	3	<1	43	N.C.	N.C.	1.4	62	1,080	9.4
11/15/2018	Peak	30,859	2	<0.3	N.A.	0.4	<0.1	0.7	<0.1	8	3	<1	44	N.C.	N.C.	1.1	134	942	8.4
11/15/2018	Falling	13,703	1	<0.3	N.A.	0.4	<0.1	0.5	<0.1	4	3	<1	36	<5	1120	0.9	148	159	7.1
1/4/2019	Rising	4,081	1	<0.3	N.A.	1.3	<0.1	<0.5	<0.1	3	2	<1	17	N.C.	N.C.	1.3	153	130	2.74
1/4/2019	Peak	15,692	1	<0.3	N.A.	0.7	<0.1	0.5	<0.1	14	4	<1	23	N.C.	N.C.	1.2	78	69.6	8.79
1/4/2019	Falling	6,177	1	<0.3	N.A.	0.9	<0.1	<0.5	<0.1	2	3	<1	16	<5	8.5	0.9	112	105	3.09
2/20/2019	Rising	4,191	<1	<0.3	N.A.	1.1	<0.1	0.5	<0.1	6	3	<1	24	N.C.	N.C.	1.6	192	1,750	3.33
2/20/2019	Peak	11,959	<1	<0.3	N.A.	0.8	<0.1	0.5	<0.1	6	4	<1	37	N.C.	N.C.	1.3	158	900	8.63
2/20/2019	Falling	5,682	<1	<0.3	N.A.	0.8	<0.1	0.5	<0.1	4	<2	<1	23	<5	25.3	1.3	140	527	3.81
6/10/2019	Rising	3,418	<1	0.09	N.A.	0.9	0.04	0.5	0.02	5	<2	<1	24	N.C.	N.C.	1.4	182	147	5.73
6/10/2019	Peak	20,179	4	0.1	N.A.	0.4	0.08	1.1	0.12	58	<4	<2	77	N.C.	N.C.	1.5	92	66.5	18.4
6/10/2019	Falling	5,196	1	0.07	N.A.	0.5	0.07	0.6	0.02	3	<2	<1	23	<5	291	1.1	110	87.3	5.04
6/12/2019	Rising	6,364	2	0.17	N.A.	0.7	<0.05	0.7	0.08	37	<4	<2	46	N.C.	N.C.	1.4	146	120	16.9
6/12/2019	Peak	18,656	3	0.11	N.A.	0.2	0.05	1.1	0.13	48	9	2	77	N.C.	N.C.	1.3	70	48.2	19.1
6/12/2019	Falling	9,326	2	0.08	N.A.	0.2	0.07	0.8	0.05	10	<4	<2	24	<5	517	1	65	52.8	10.7

N.C. = Sample Not Collected
N.A. = Parameter Not Analyzed

Table 4-1. (Continued)

Storm Date	Limb	Dis-charge (cf)	5-Day BOD	Ammo-nia	Nitrate	Nitrate + Nitrite	Ortho-phos-phate	TKN	Total P	TSS	Copper (µg/l)	Lead (µg/l)	Zinc (µg/l)	TPH	*E. coli* (MPN/ 100 ml)	Total Nitro-gen	Hard-ness	Chlor-ide	Turbid-ity (NTU)
Station WC004																			
7/17/2018	Rising	8,322	9.27	0.14	0.7	0.67	0.012	2.3	0.75	364	48.3	17.6	265	<5	>2420	2.97	81.7	78.1	140
7/17/2018	Peak	27,010	3.56	0.11	0.47	0.43	0.018	0.87	0.055	29	<40	<3	24	N.C.	N.C.	1.3	21.8	28	11
7/17/2018	Falling	11,529	2.23	0.18	0.38	0.37	0.0075	0.75	<0.1	10.5	<40	<3	19.6	N.C.	N.C.	1.12	29	35	1.8
9/17/2018	Rising	21,906	2	<0.3	N.A.	0.4	<0.1	0.7	<0.1	7	6	0.4	16	N.C.	N.C.	1.1	56	62.2	2.3
9/17/2018	Peak	62,856	2	<0.3	N.A.	0.2	<0.1	0.8	<0.1	26	7	1	17	<5	>2420	1	24	18	12.9
9/17/2018	Falling	18,340	1	<0.3	N.A.	0.4	<0.1	0.6	<0.1	6	5	<1	17	N.C.	N.C.	1	40	39.9	5.6
10/26/2018	Rising	15,823	3	<0.3	N.A.	0.5	<0.1	1.2	0.12	45	11	2	118	<5	172	1.7	60	56.8	3.49
10/26/2018	Peak	25,867	1	<0.3	N.A.	0.3	<0.1	0.8	<0.1	12	6	<1	118	N.C.	N.C.	1.1	<50	32.2	2.73
10/26/2018	Falling	5,373	1	<0.3	N.A.	0.5	<0.1	0.7	<0.1	3	6	<1	106	N.C.	N.C.	1.2	10	47.8	2.86
11/15/2018	Rising	1,453	1	<0.3	N.A.	0.7	<0.1	0.8	<0.1	7	5	<1	50	N.C.	N.C.	1.5	176	829	5.7
11/15/2018	Peak	10,403	1	<0.3	N.A.	0.2	<0.1	<0.5	<0.1	4	5	<1	38	N.C.	N.C.	0.2	40	162	6.6
11/15/2018	Falling	780	1	<0.3	N.A.	0.3	<0.1	<0.5	<0.1	2	4	1	44	<5	866	0.3	36	91	4.5
1/4/2019	Rising	2,372	1	<0.3	N.A.	0.9	<0.1	0.6	<0.1	5	6	<1	25	N.C.	N.C.	1.5	93	84.9	4.22
1/4/2019	Peak	8,344	1	<0.3	N.A.	0.5	<0.1	0.6	<0.1	8	6	<1	31	N.C.	N.C.	1.1	49	47.9	5.98
1/4/2019	Falling	3,678	1	<0.3	N.A.	0.8	<0.1	<0.5	<0.1	1	4	<1	21	<5	13.2	0.8	86	78.3	3.93
2/20/2019	Rising	3,794	<1	<0.3	N.A.	0.9	<0.1	0.7	<0.1	9	4	<1	39	N.C.	N.C.	1.6	136	880	9.49
2/20/2019	Peak	8,166	1	<0.3	N.A.	0.6	<0.1	0.9	<0.1	11	5	<1	45	N.C.	N.C.	1.5	136	1,200	15.4
2/20/2019	Falling	3,913	1	<0.3	N.A.	0.8	<0.1	0.8	<0.1	10	4	<1	52	<5	387	1.6	108	692	13.3
6/10/2019	Rising	3,145	1	0.06	N.A.	1.8	0.04	0.9	0.04	12	3	<1	42	N.C.	N.C.	2.7	183	142	6.06
6/10/2019	Peak	15,016	3	0.16	N.A.	0.4	0.06	1.3	0.07	12	<4	<2	51	N.C.	N.C.	1.7	79	38.7	8.35
6/10/2019	Falling	4,656	2	0.09	N.A.	0.8	0.04	1	0.04	5	<4	<2	28	<5	435	1.8	82	69.9	5.96
6/12/2019	Rising	5,300	3	0.16	N.A.	0.3	0.06	1.4	0.12	23	8	2	49	N.C.	N.C.	1.7	57	44.9	11.9
6/12/2019	Peak	11,596	2	0.12	N.A.	<0.2	0.06	1	0.09	9	5	<1	33	N.C.	N.C.	1	31	26.3	8.28
6/12/2019	Falling	7,259	2	0.13	N.A.	0.2	0.06	0.9	0.04	6	3	<1	32	<5	166	1.1	34	28.2	6.39

N.C. = Sample Not Collected
N.A. = Parameter Not Analyzed

Table 4-2. Stormflow filtered water chemistry results, July 2018 – June 2019. All concentrations are in units of mg/L unless indicated.

Station		WC002				WC003				WC004			
			Dissolved				Dissolved				Dissolved		
Storm Date	Limb	Dis-charge (cf)	Nitrate + Nitrite	TKN	Total P	Dis-charge (cf)	Nitrate + Nitrite	TKN	Total P	Dis-charge (cf)	Nitrate + Nitrite	TKN	Total P
7/17/2018*	Rising	40,713	1.1	<2.5	<0.1	10,847	1.1	0.97	<0.1	8,322	0.68	1.1	<0.1
7/17/2018*	Peak	143,606	0.68	1	<0.1	30,535	0.75	1	<0.1	27,010	0.48	1	<0.1
7/17/2018*	Falling	66,217	0.57	0.7	<0.1	12,851	0.57	<0.83	<0.1	11,529	0.35	0.78	<0.1

*Only the July storm had filtered water samples analyzed.

Table 4-3. Baseflow water chemistry results, July 2018 – June 2019. All concentrations are in units of mg/L unless indicated.

Baseflow Date*	5-Day BOD	Ammo nia	Nitrate	Nitrate + Nitrite	Ortho-phos-phate	TKN	Total P	TSS	Cop-per (µg/l)	Lead (µg/l)	Zinc (µg/l)	TPH	*E. coli* (MPN/ 100 ml)	Total Nitro-gen	Hard ness	Chlor-ide	Tur-bidity
Station WC002																	
8/28/2018	<2	<0.3	N.A.	1.5	<0.1	<0.5	<0.1	1	0.6	<0.06	15	<5	613	1.5	181	142	1.96
10/18/2018	<1	0.3	N.A.	1.8	<0.1	0.5	<0.1	<1	0.5	<0.06	23	<5	70.8	2.3	190	139	0.94
11/29/2018	<1	<0.3	N.A.	1.9	<0.1	<0.5	<0.1	<1	0.2	<0.06	19	<5	37.9	1.9	150	119	1.32
12/18/2018	16	<0.3	N.A.	1.8	<0.1	0.7	<0.1	1	<0.2	<0.06	23	<5	1,200	2.5	142	118	1.64
1/22/2019	1	<0.3	N.A.	2.2	<0.1	<0.5	<0.1	1	0.4	<0.06	33	<5	13.5	2.2	154	216	1.15
2/27/2019	1	<0.3	N.A.	2	<0.1	<0.5	<0.1	4	<2	<1	22	<5	9.6	2	147	228	1.89
3/26/2019	<1	<0.3	N.A.	2.4	0.07	0.4	0.01	2	0.8	<1	18	<5	83.6	2.8	138	142	2.12
4/23/2019	1	0.27	N.A.	1.6	0.02	1.2	0.02	6	1	<1	15	<5	81.6	2.8	159	138	2.49
5/22/2019	<1	0.34	N.A.	1.7	0.03	0.4	0.02	3	0.3	<1	12	<5	96	2.1	157	131	2.66
6/27/2019	<1	0.35	N.A.	1.5	0.09	0.6	<0.05	1	0.4	<1	13	<5	488	2.1	155	117	1.82
Station WC003																	
8/28/2018	<2	<0.3	N.A.	1.2	<0.1	<0.5	<0.1	1	0.5	<0.06	18	<5	770	1.2	204	187	3.81
10/18/2018	<1	<0.3	N.A.	1.3	<0.1	0.5	<0.1	<1	0.5	<0.06	21	<5	27.9	1.8	185	169	1.09
11/29/2018	<1	<0.3	N.A.	1.3	<0.1	<0.5	<0.1	1	0.4	<0.06	26	<5	37.3	1.3	158	140	1.41
12/18/2018	4	0.3	N.A.	1.3	<0.1	0.9	<0.1	1	<0.2	<0.06	28	<5	>2420	2.2	154	136	1.77
1/22/2019	1	<0.3	N.A.	1.4	<0.1	<0.5	<0.1	2	0.6	<0.06	41	<5	19.7	1.4	174	239	1.6
2/27/2019	1	<0.3	N.A.	1.3	<0.1	<0.5	0.28	<1	<2	<1	27	<5	6.3	1.3	159	319	1.85
3/26/2019	<1	<0.3	N.A.	1.2	0.02	0.3	0.01	<1	<2	<1	17	<5	40.4	1.5	158	181	2.58
4/23/2019	<1	0.1	N.A.	0.9	0.009	0.6	<0.1	14	2	0.3	31	<5	167	1.5	184	170	2.52
5/22/2019	1	0.12	N.A.	1	0.03	<0.5	<0.05	3	<2	<1	22	<5	128	1	170	149	2.86
6/27/2019	<1	<0.3	N.A.	1	<0.07	0.6	<0.05	10	0.6	0.06	30	<5	488	1.6	183	148	4.55

Table 4-3. (Continued)

Baseflow Date*	5-Day BOD	Ammonia	Nitrate	Nitrate + Nitrite	Ortho-phosphate	TKN	Total P	TSS	Copper (µg/l)	Lead (µg/l)	Zinc (µg/l)	TPH	*E. coli* (MPN/ 100 ml)	Total Nitrogen	Hardness	Chloride	Turbidity
Station WC004																	
8/28/2018	<2	<0.3	N.A.	3.2	<0.1	<0.5	<0.1	14	1	0.6	25	<5	166	3.2	280	294	1.2
10/18/2018	<1	<0.3	N.A.	2.9	<0.1	0.5	<0.1	<1	0.6	<0.06	23	<5	866	3.4	243	261	0.23
11/29/2018	<1	<0.3	N.A.	2.4	<0.1	<0.5	<0.1	1	0.6	<0.06	18	<5	166	2.4	182	201	0.665
12/18/2018	<1	<0.3	N.A.	2.2	<0.1	<0.5	<0.1	1	0.5	<0.06	24	<5	61.7	2.2	167	179	0.938
1/22/2019	1	<0.3	N.A.	2.8	<0.1	<0.5	<0.1	3	0.6	<0.06	25	<5	105	2.8	203	343	0.889
2/27/2019	1	<0.3	N.A.	2.6	<0.1	<0.5	<0.1	<1	<2	<1	27	<5	7.4	2.6	193	314	0.428
3/26/2019	<1	<0.3	N.A.	2.5	0.02	0.4	0.02	1	1	<1	19	<5	411	2.9	155	238	1.78
4/23/2019	<1	0.05	N.A.	3.1	<0.1	0.6	<0.1	<1	0.7	<1	22	<5	115	3.7	254	259	0.66
5/22/2019	<1	0.06	N.A.	3.4	0.02	0.4	<0.05	2	0.5	0.1	22	<5	214	3.8	257	231	0.48
6/27/2019	<1	<0.3	N.A.	2.8	0.08	0.6	<0.05	1	0.6	<1	21	<5	1,550	3.4	247	211	0.58

* No baseflow was collected in July due to laboratory transition and September due to extreme rainfall without ample dry time
N.A. = Parameter Not Analyzed

TPH was not detected in any baseflow samples collected from the study area during the monitoring period.

4.3 BASEFLOW MEAN AND STORM EVENT MEAN CONCENTRATION DATA

EMC values for each parameter were calculated at each station for each storm event (Table 4-4). Average annual baseflow concentration and storm EMC values were calculated for each pollutant at each station (Table 4-5). Average concentration data computed for storm and baseflows over the course of a year were used to characterize pollutant concentrations during average baseflow conditions or an average stormflow event (Figures 4-1 through 4-6). Total annual and seasonal baseflow mean concentrations, storm EMCs, and loads for each pollutant are presented in Appendix D and Appendix E, respectively.

Under baseflow conditions, average concentrations of combined nitrate plus nitrite, chloride, lead, and copper were highest at Station WC004 compared to the other two stations downstream. *E. coli* concentrations were higher at Station WC004 than at Station WC002, as in years past, but were slightly lower than the *E. coli* concentrations found at Station WC003. The higher concentrations of *E. coli* and combined nitrate plus nitrite at Station WC004 may indicate a continued nutrient and septic input in the vicinity of the station. Higher average chloride values may be the result of mobilization of chloride in groundwater as a result of runoff from legacy deicing compound application at the Festival of Bel Air Shopping Center and along Route 24. Samples collected at Station WC003 had the highest average concentrations of total phosphorus, TSS, and zinc during baseflow conditions. Station WC002 samples had the highest average concentrations of BOD, ammonia, and TKN at baseflow conditions.

Under stormflow conditions, average EMCs were highest at Station WC004 for zinc (Figures 4-1 through 4-6), which may be the result of washing of accumulated pollutants in runoff from paved parking areas at Festival of Bel Air and the roadbed of Route 24. Average EMCs for BOD, ammonia, nitrate plus nitrite, total phosphorus, TSS, chloride, copper, lead and *E. coli* were highest at Station WC002. At Station WC003, only orthophosphate and TKN were highest of the three stations. All average stormflow EMCs exceeded corresponding baseflow mean concentrations at all stations except combined nitrate plus nitrite and other specific exceptions. In isolated cases, such as for ammonia at Stations WC002 and WC003 and chloride at Station WC004, mean baseflow concentrations exceeded corresponding storm EMCs. Note also that the annual average storm EMCs include results from the previous laboratory (July 2018 storm only), which used reportable detection limits that were lower than the current laboratory for parameters such as BOD, ammonia, orthophosphate, and lead. Since no baseflow sample was taken in July, the relationship between the average annual EMCs and baseflow MCs for these four parameters may not reflect actual conditions. Average EMCs of all pollutants at all stations were lower than Maryland and national average values, except for combined nitrate plus nitrite, which exceeded the national average value at Station WC002 (Table 4-5).

Table 4-4. Storm event mean concentration results (mg/L except where indicated), July 2018 – June 2019 (non-detects set to zero).

Storm Date	Rainfall (inches)	5-Day BOD	Ammo-nia	Nitrate	Nitrate + Nitrite	Orthophos-phate	TKN	Total P	TSS	Chloride	Copper (µg/l)	Lead (µg/l)	Zinc (µg/l)
Station WC002													
7/17/2018	1.78	6.62	0.13	0.77	0.74	N.A.	1.42	0.20	131.50	36.04	9.96	2.16	50.00
9/17/2018	2.52	3.65	0.00	N.A.	0.51	0.00	1.13	0.17	84.97	18.74	14.19	2.44	36.56
10/26/2018	1.3	3.05	0.00	N.A.	0.56	0.00	0.85	0.10	29.37	48.48	8.05	1.13	76.05
11/15/2018	1.16	2.44	0.07	N.A.	0.57	0.00	0.71	0.00	11.43	724.02	5.20	0.00	51.56
1/4/2019	0.32	1.00	0.07	N.A.	1.11	0.00	0.28	0.00	6.10	77.21	8.94	0.00	18.44
2/20/2019	0.15	0.00	0.00	N.A.	1.16	0.00	0.26	0.00	5.41	1,334.98	1.31	0.00	32.69
6/10/2019	0.48	1.26	0.10	N.A.	0.83	0.05	0.54	0.04	8.48	70.81	0.00	0.00	18.91
6/12/2019	0.58	S.M.	S.M.	S.M.	S.M.	S.M.	S.M.	S.M.	S.M.	S.M.	S.M.	S.M.	S.M.
Station WC003													
7/17/2018	1.78	6.39	0.16	0.81	0.81	N.A.	1.70	0.26	147.53	51.86	15.33	3.88	67.01
9/17/2018	2.52	1.88	0.00	N.A.	0.41	0.00	0.85	0.00	24.93	33.89	9.37	0.83	19.76
10/26/2018	1.3	2.28	0.00	N.A.	0.44	0.00	0.90	0.02	22.68	61.58	7.55	0.41	44.56
11/15/2018	1.16	1.61	0.00	N.A.	0.45	0.00	0.63	0.00	7.73	745.33	3.00	0.00	41.71
1/4/2019	0.32	1.00	0.00	N.A.	0.84	0.00	0.30	0.00	9.41	87.53	3.45	0.00	20.39
2/20/2019	0.15	0.00	0.00	N.A.	0.86	0.00	0.50	0.00	5.48	966.09	2.77	0.00	30.86
6/10/2019	0.48	2.98	0.09	N.A.	0.48	0.07	0.94	0.09	41.78	79.81	0.00	0.00	60.96
6/12/2019	0.58	2.54	0.11	N.A.	0.29	0.05	0.94	0.10	35.64	62.75	4.89	1.09	56.86
Station WC004													
7/17/2018	1.78	4.25	0.13	0.49	0.46	N.A.	1.09	0.16	83.94	38.62	8.58	3.13	65.72
9/17/2018	2.52	1.82	0.00	N.A.	0.28	0.00	0.74	0.00	18.41	31.29	6.43	0.69	16.79
10/26/2018	1.3	1.67	0.00	N.A.	0.39	0.00	0.92	0.04	22.07	42.25	7.68	0.67	116.63
11/15/2018	1.16	1.00	0.00	N.A.	0.26	0.00	0.09	0.00	4.22	234.31	4.94	0.06	39.75
1/4/2019	0.32	1.00	0.00	N.A.	0.64	0.00	0.45	0.00	5.72	61.77	5.49	0.00	27.46
2/20/2019	0.15	0.76	0.00	N.A.	0.72	0.00	0.83	0.00	10.28	998.28	4.51	0.00	45.29
6/10/2019	0.48	2.52	0.13	N.A.	0.67	0.05	1.18	0.06	10.57	59.31	0.41	0.00	45.07
6/12/2019	0.58	2.22	0.13	N.A.	0.13	0.06	1.06	0.08	11.17	30.95	5.06	0.44	36.21

S.M. = Sampler Malfunction
N.A. = Parameter Not Analyzed

Table 4-5. Average storm EMCs and baseflow mean concentrations, Wheel Creek Watershed, July 2018 – June 2019 (non-detects set to zero). All concentrations are in units of mg/L unless indicated.

Station	5-Day BOD	Ammonia	Nitrate	Nitrate + Nitrite	Ortho-phos-phate	TKN	Total P	TSS	Chlor-ide	Copper (µg/l)	Lead (µg/l)	Zinc (µg/l)	TPH	*E. coli* (MPN/ 100 ml)
Storm Event Mean Concentrations														
WC002	2.57	0.05	0.77	0.78	0.01	0.74	0.07	39.61	330.04	6.81	0.82	40.60	0.00	1,167.86
WC003	2.34	0.05	0.81	0.57	0.02	0.85	0.06	36.90	261.11	5.79	0.78	42.77	0.00	870.98
WC004	1.91	0.05	0.49	0.44	0.02	0.80	0.04	20.80	187.10	5.39	0.62	49.11	0.00	859.90
MD avg[a]	14.44	N.R.	N.R.	0.85	N.R.	1.94	0.33	66.57	N.R.	17.9	12.5	143.3	N.R.	N.R.
NSQD[b]	16.943	N.R.	N.R.	1.587	N.R.	2.921	0.412	111.295	N.R.	42	41	250	2.759	N.R.
NURP[c]	9	N.R.	N.R.	0.68	N.R.	1.5	0.33	100	N.R.	34	144	160	N.R.	N.R.
Baseflow Mean Concentrations														
WC002	1.90	0.13	N.A.	1.84	0.02	0.38	0.01	1.90	149.00	0.42	0.00	19.30	0.00	269.40
WC003	0.70	0.05	N.A.	1.19	0.01	0.29	0.03	3.20	183.80	0.46	0.04	26.10	0.00	410.46
WC004	0.20	0.01	N.A.	2.79	0.01	0.25	0.00	2.30	253.10	0.61	0.07	22.60	0.00	366.21

N.R. = Reference data not available.
N.A. = Parameter Not Analyzed
[a] = Maryland State average values from Bahr 1997.
[b] = National Stormwater Quality Database values for Maryland from Pitt 2008.
[c] = National Urban Runoff Program values from U.S. EPA 1983.

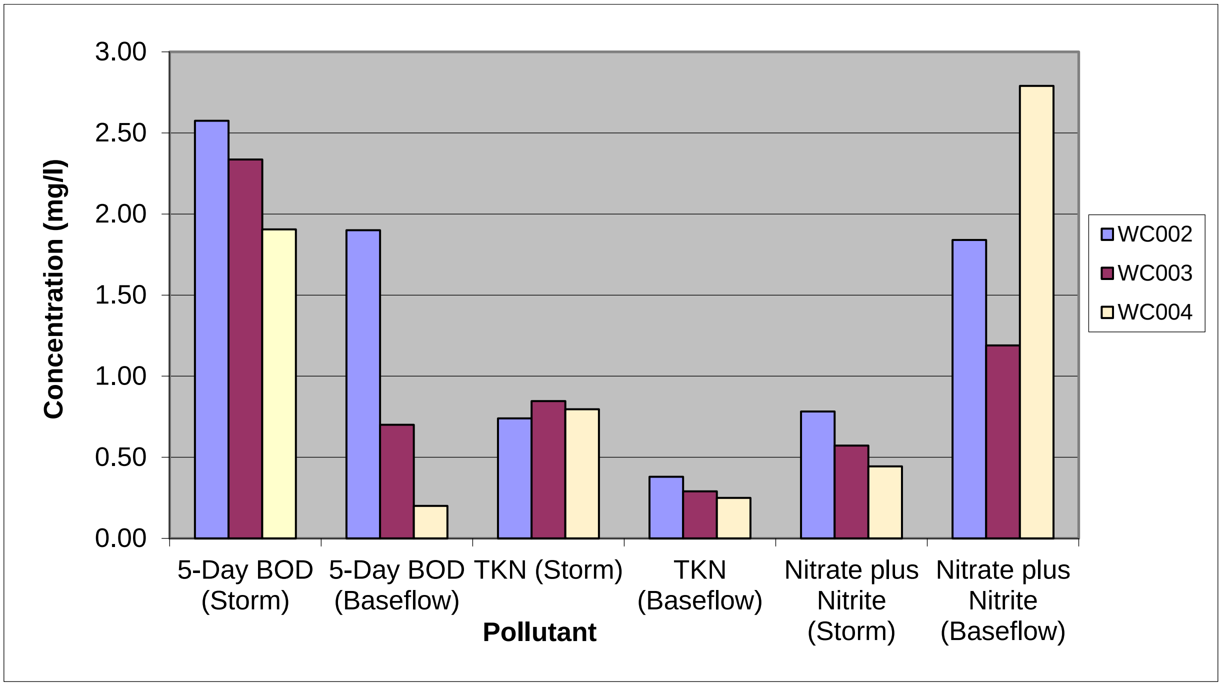

Figure 4-1. Nitrogen and 5-day BOD average storm event mean and baseflow mean concentrations in Wheel Creek, July 2018 – June 2019

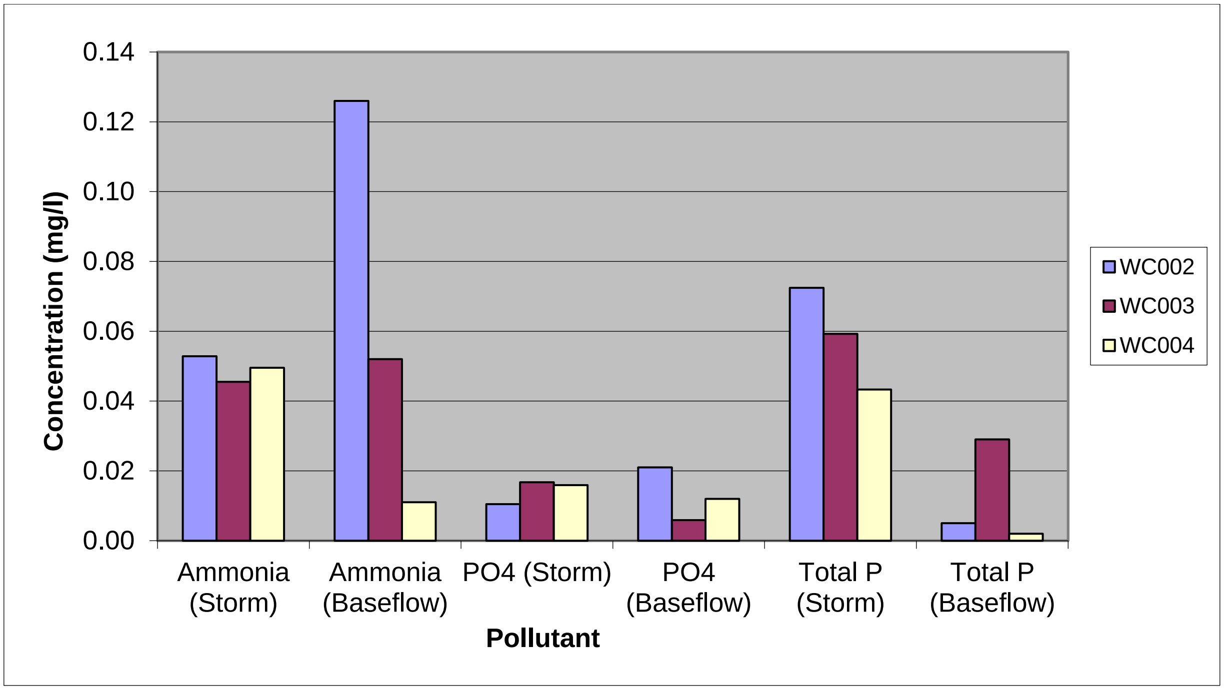

Figure 4-2. Ammonia and phosphorus average storm event mean and baseflow mean concentrations in Wheel Creek, July 2018 – June 2019

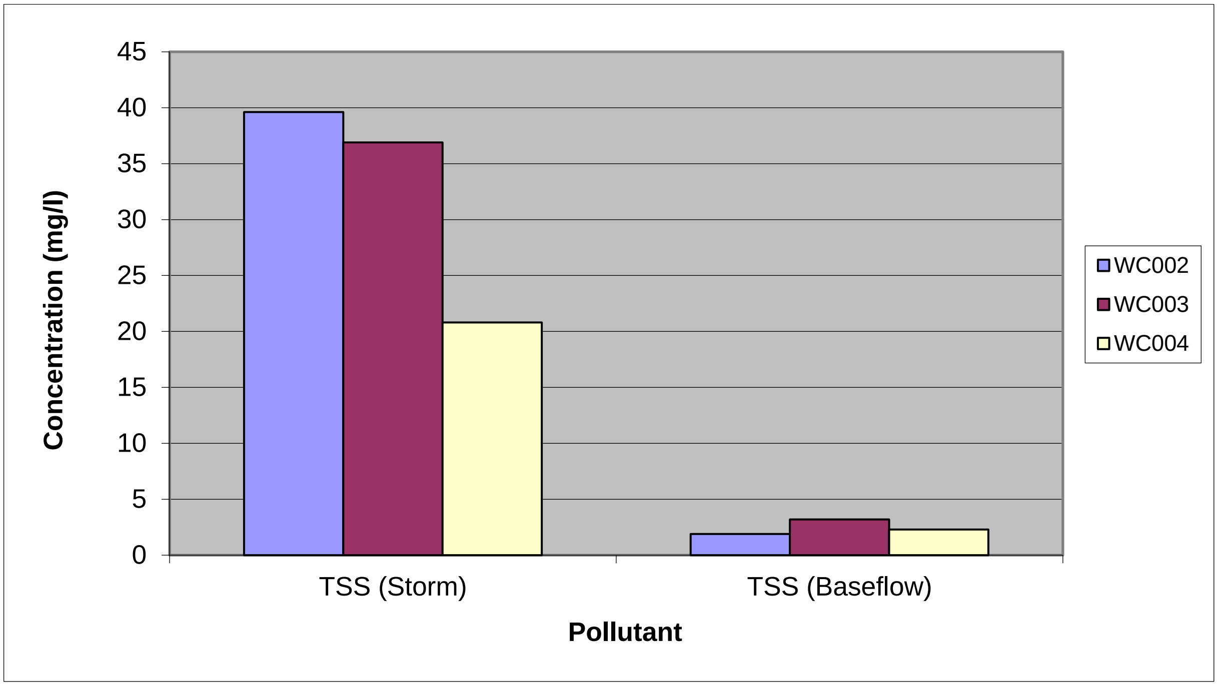

Figure 4-3. TSS average storm event and baseflow mean concentrations in Wheel Creek, July 2018 – June 2019

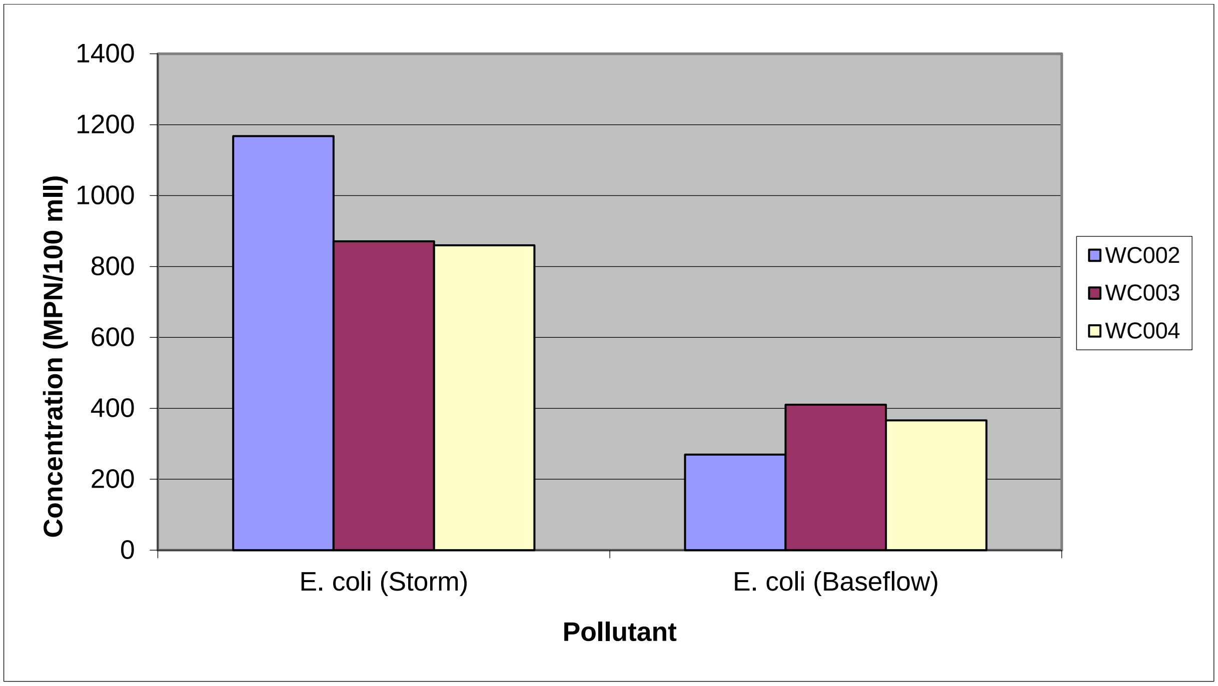

Figure 4-4. *E. coli* average storm and baseflow mean concentrations in Wheel Creek, July 2018 – June 2019

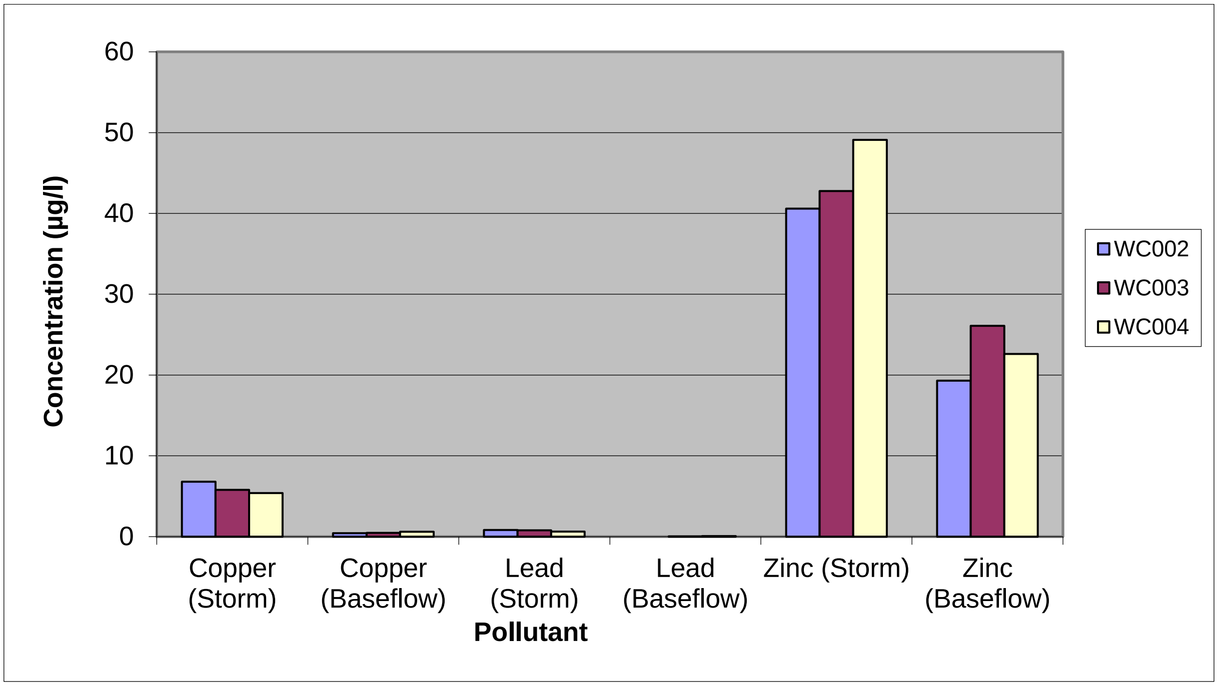

Figure 4-5. Metal average storm event mean and baseflow mean concentrations in Wheel Creek, July 2018 – June 2019

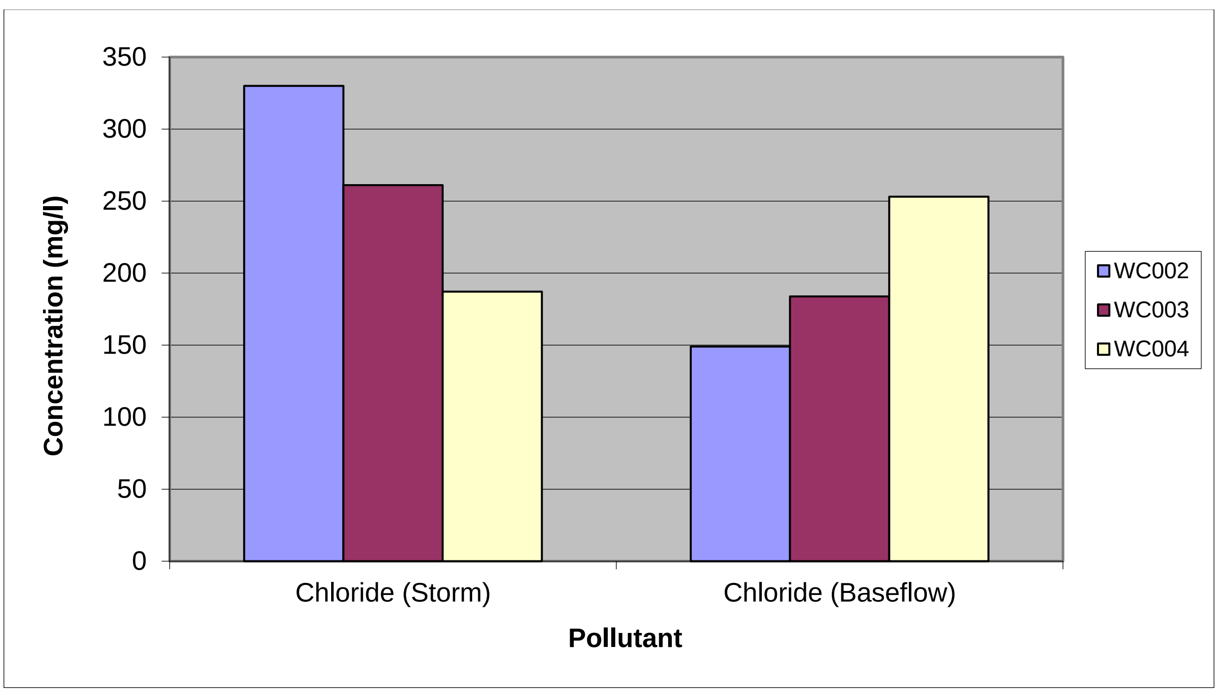

Figure 4-6. Chloride storm event mean and baseflow mean concentrations in Wheel Creek, July 2018 – June 2019

Time-series plots of the annual average concentrations of pollutants measured from 2010 to FY2019 are shown in Figure 4-7 through Figure 4-15 and are presented to characterize change, on an annual basis, in pollutant concentrations as restoration projects were implemented in the watershed. Plots of average annual storm EMCs and baseflow MCs (with individual non-detect concentrations set to zero) are presented for the following pollutants: nitrate-nitrite, TKN, total phosphorus, TSS, copper, zinc, lead, ammonia, and BOD. Note that data from the shortened reporting period comprising the first six months of calendar year 2015 were not included in the plots.

Visually, some of the plots show a potential change in long-term trend in annual concentration data that can be associated with completion of restoration projects in the watershed. For nitrate plus nitrite, while FY2019 showed a slight increase in storm EMCs and baseflow MCs at Stations WC002 and WC003, the prevailing trend continues gradually downward at all stations since approximately 2014, coinciding with the completion of most of the restoration projects. Storm EMCs for several of the parameters, such as total phosphorus, TSS, copper, and BOD show signs of gradually increasing trend until approximately FY2017 and then abruptly falling in FY2018 and FY2019. Average storm EMCs for TKN behaved similarly in FY2018, but rebounded in FY2019 at all stations. Conversely, EMCs for ammonia gradually decreased through FY2017, then abruptly increased in FY2018 before falling in FY2019. Lead and zinc showed no trend, although lead EMCs for two out of three stations declined in FY2019. The time series data may indicate that the restoration efforts, in concert, are having the desired effect of reducing nutrient and TSS concentrations in storm flow. Additional monitoring is needed to distinguish a permanent change in long-term pollutant concentrations.

4.4 STORMFLOW POLLUTANT LOADING DATA

Pollutant loads for individual storms at each station were calculated from individual stormflow event mean concentration data (Table 4-6). Pollutant load represents the quantity of pollutant, in pounds, that was transported in the stream during the event. For discussion purposes, an average load was determined for each pollutant at each station for storms monitored from July 2018 through June 2019.

When comparing stations, average storm loads were highest at Station WC002 for all parameters (Table 4-7). Average loads were lowest at Station WC004 for all parameters. Since discharge volume for a given storm increases with distance downstream, maximum load results at Station WC002 are expected.

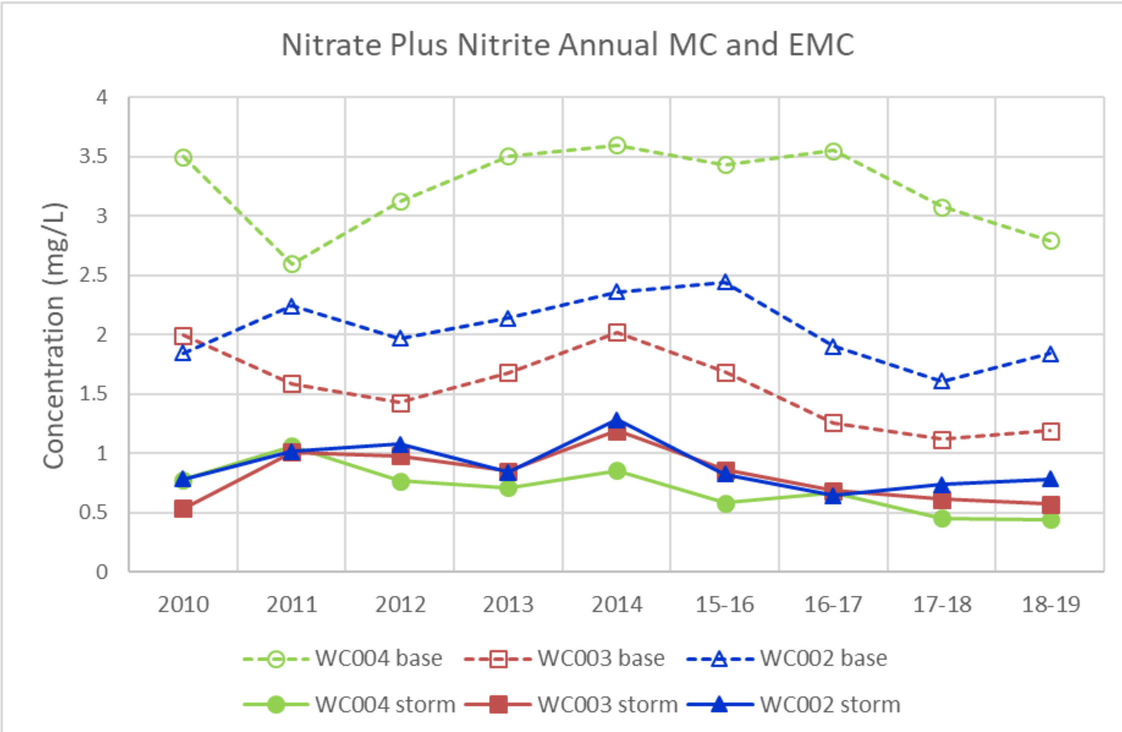

Figure 4-7. Time series plot of average annual baseflow MC and stormflow EMC for nitrate-nitrite (2010-FY2019)

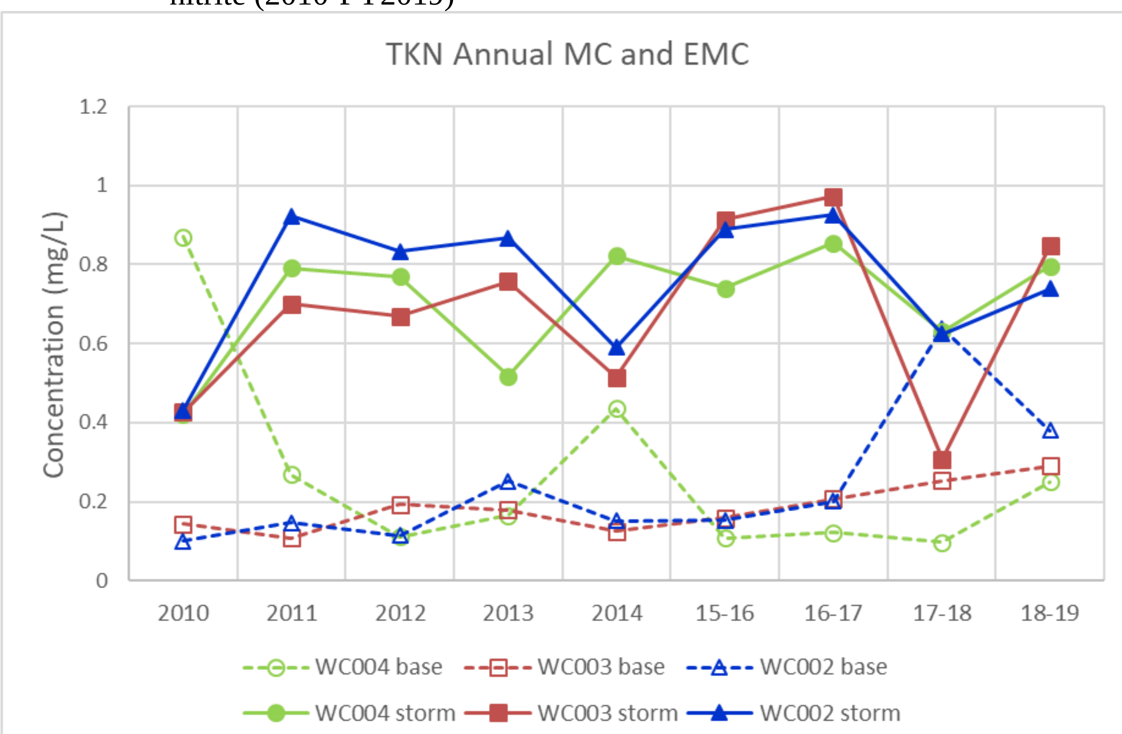

Figure 4-8. Time series plot of average annual baseflow MC and stormflow EMC for TKN (2010-FY2019)

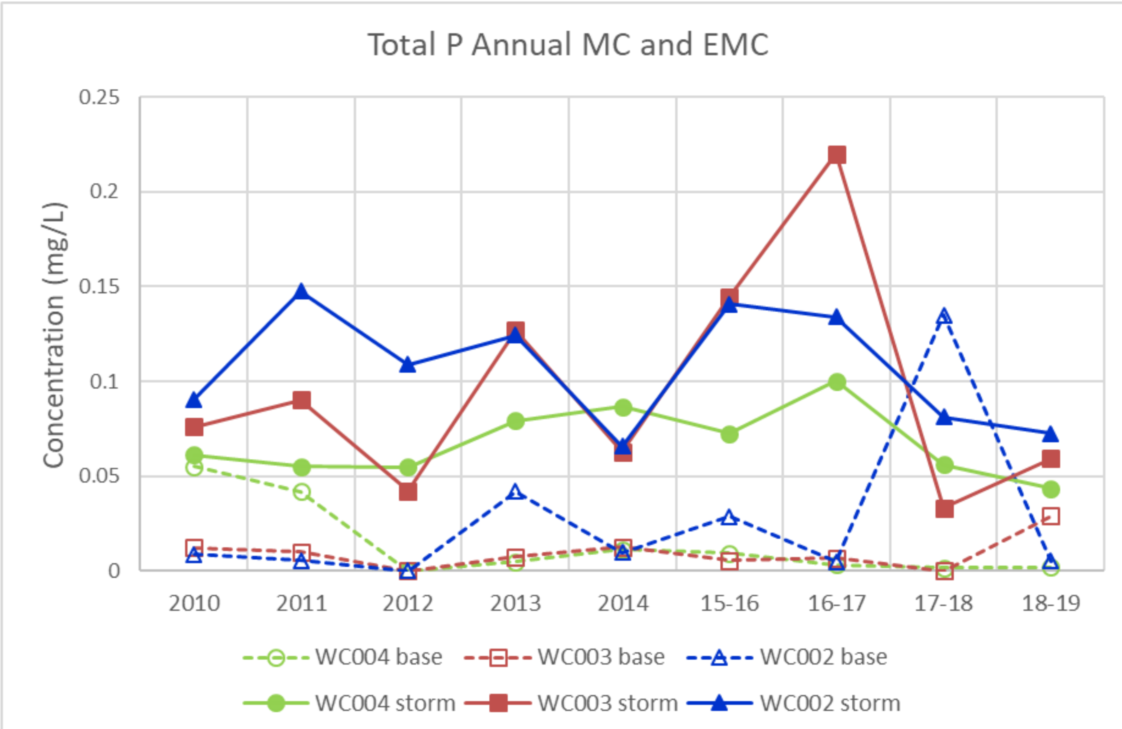

Figure 4-9. Time series plot of average annual baseflow MC and stormflow EMC for total phosphorus (2010-FY2019)

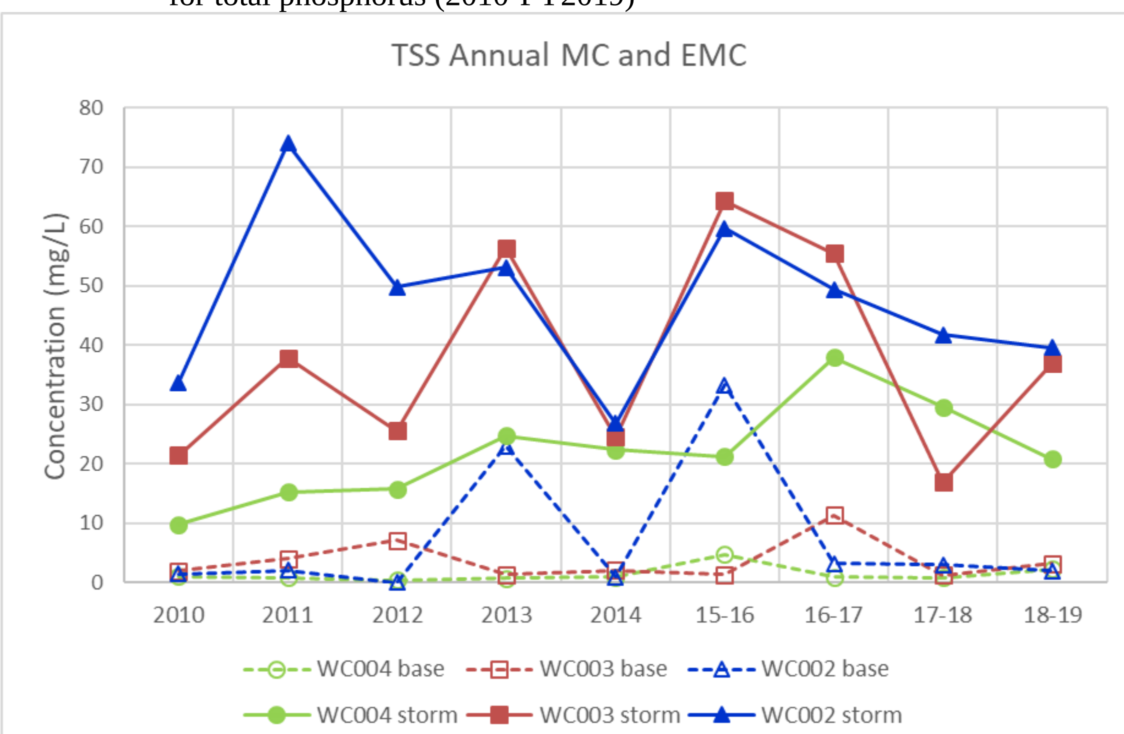

Figure 4-10. Time series plot of average annual baseflow MC and stormflow EMC for TSS (2010-FY2019)

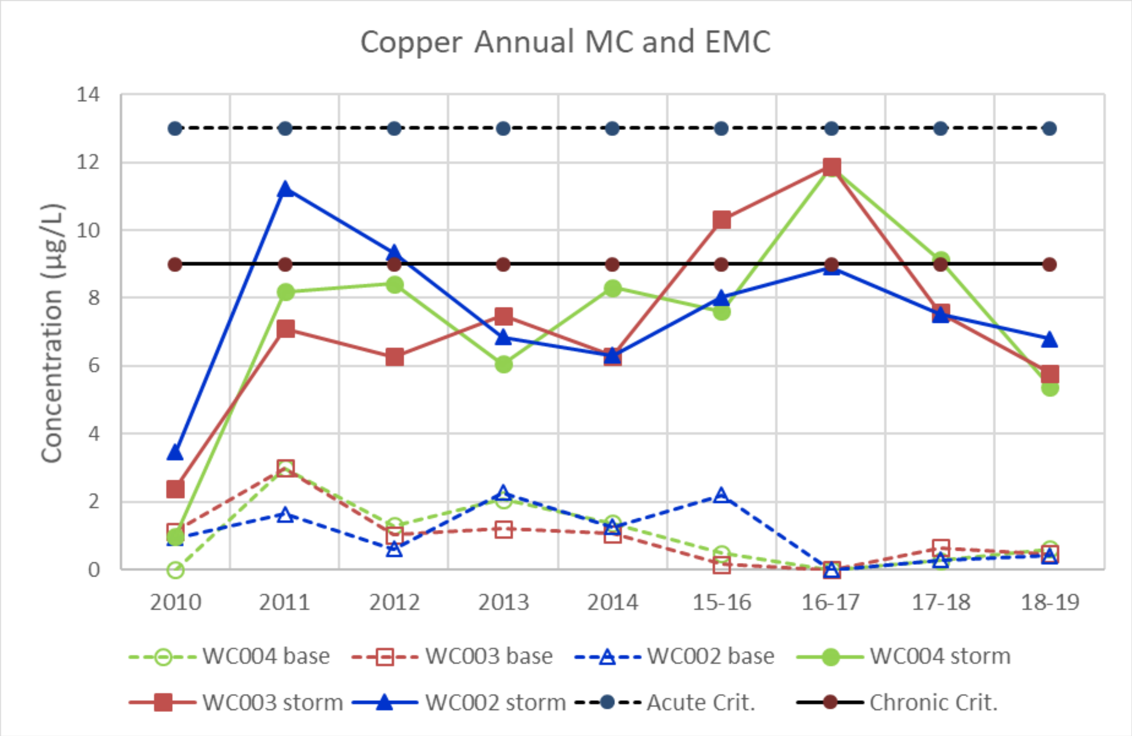

Figure 4-11. Time series plot of average annual baseflow MC and stormflow EMC for copper (2010-FY2019)

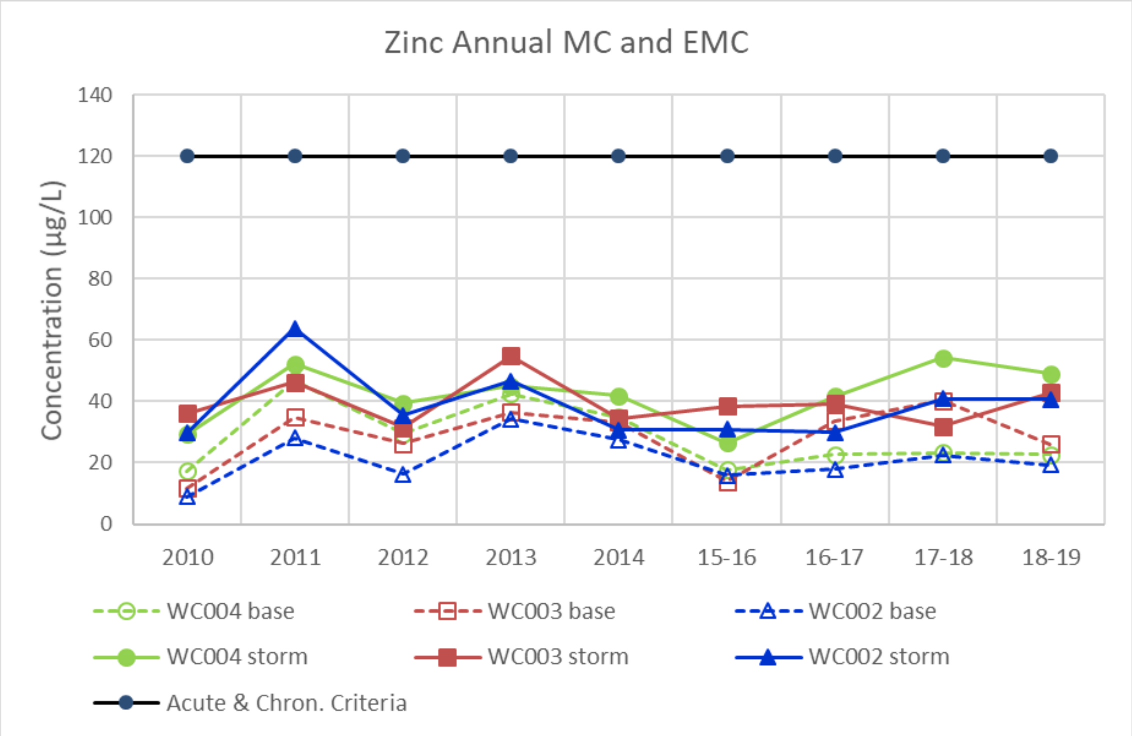

Figure 4-12. Time series plot of average annual baseflow MC and stormflow EMC for zinc (2010-FY2019)

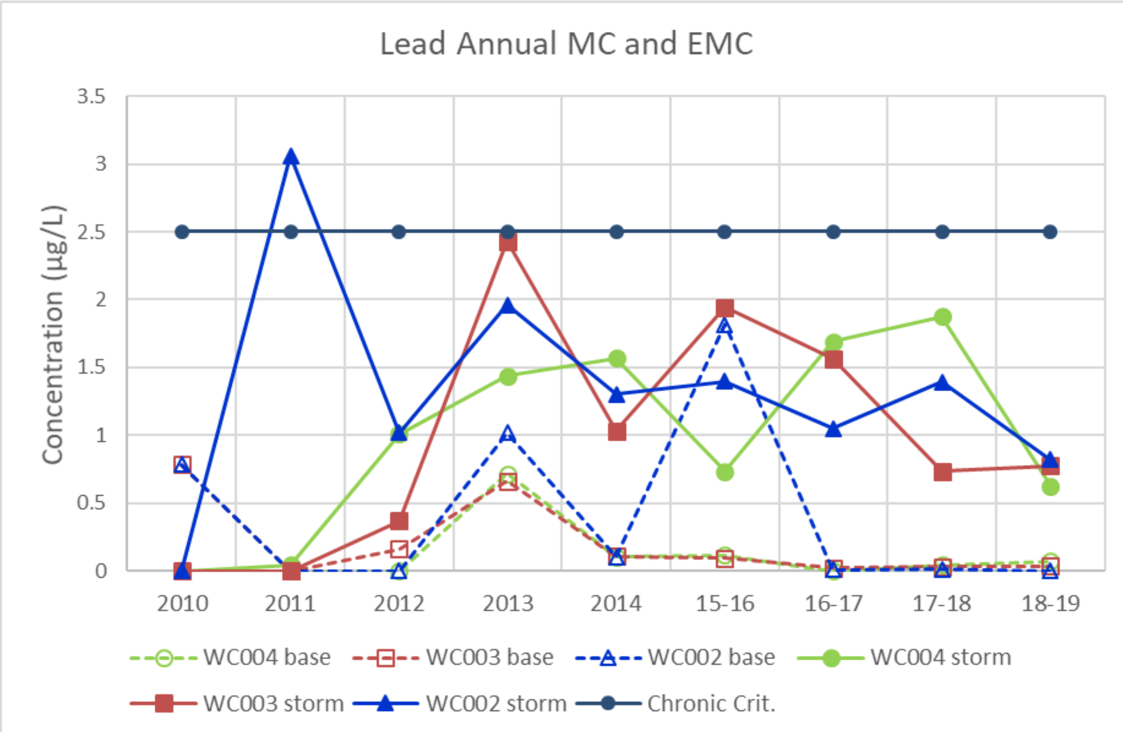

Figure 4-13. Time series plot of average annual baseflow MC and stormflow EMC for lead (2010-FY2019). Note: the acute criterion is not shown to maintain small scale.

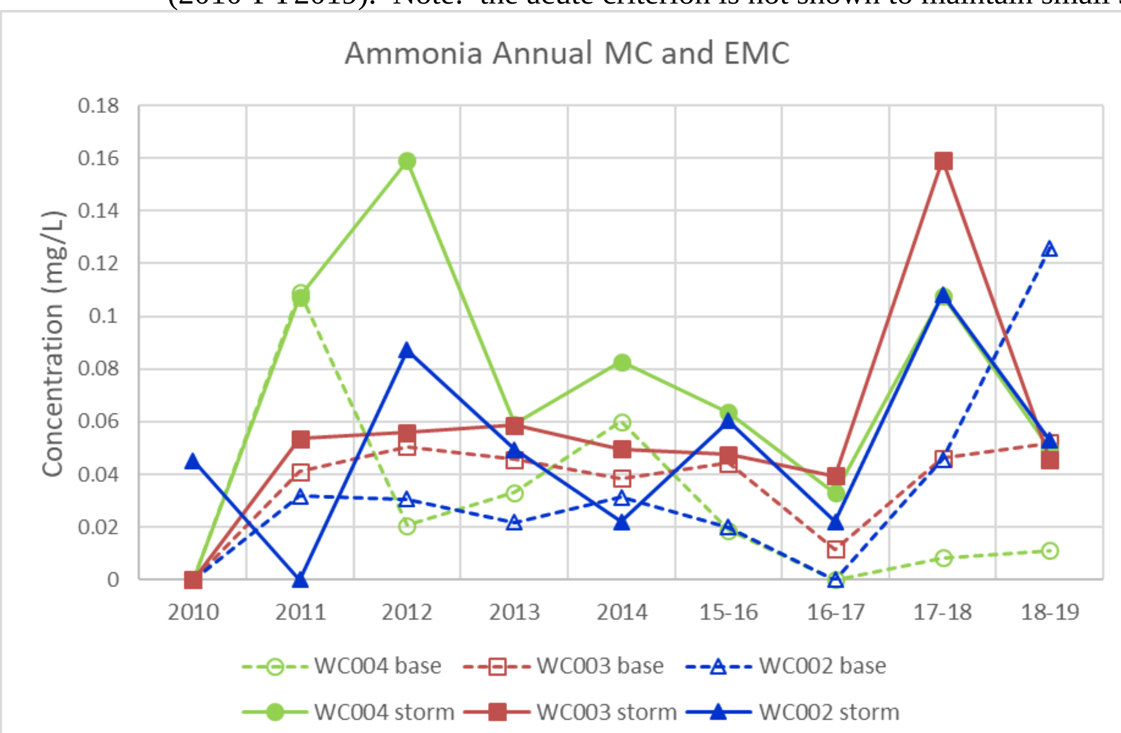

Figure 4-14. Time series plot of average annual baseflow MC and stormflow MC for ammonia (2010-FY2019)

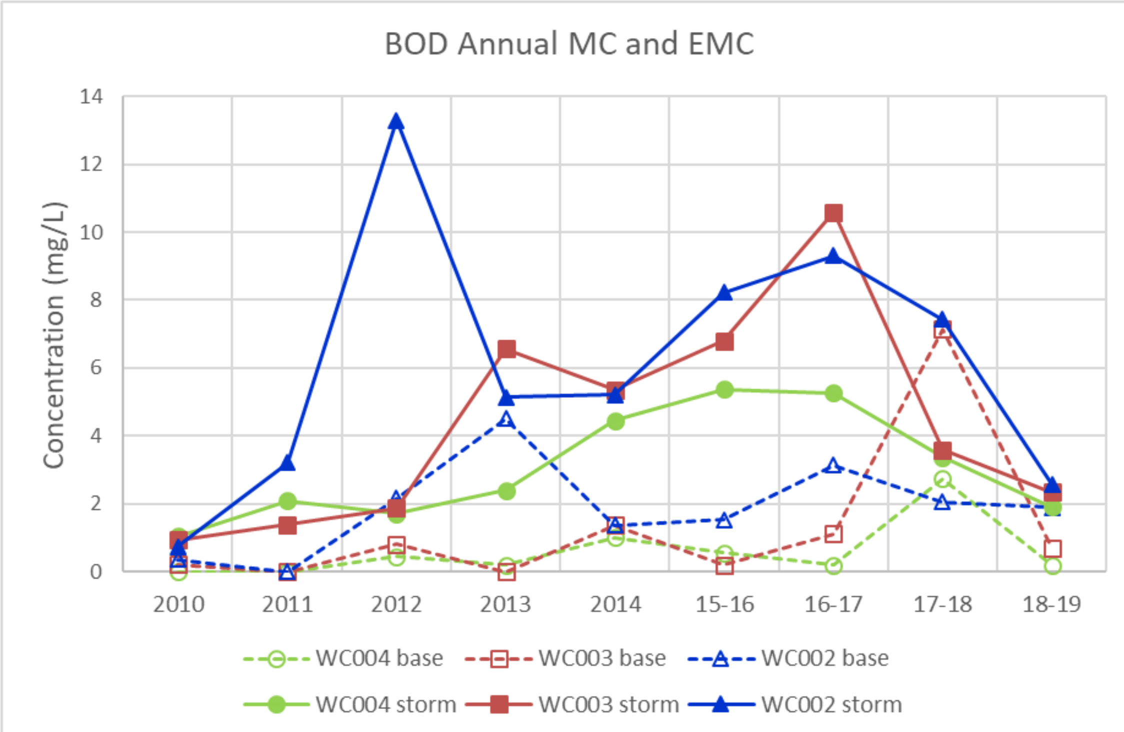

Figure 4-15. Time series plot of average annual baseflow MC and stormflow MC for BOD (2010-FY2019)

Table 4-6. Storm event pollutant loadings (lbs per event), July 2018 – June 2019 (non-detects set to zero).

Storm Date	Discharge (cf)	5-Day BOD	Ammonia	Nitrate	Nitrate + Nitrite	Ortho-phosphate	TKN	Total P	TSS	Chloride	Copper	Lead	Zinc
Station WC002													
7/17/2018	631,396	260.84	5.20	30.47	29.36	N.A.	55.88	7.80	5,183.39	1,420.65	0.39252	0.08501	1.97083
9/17/2018	1,858,690	423.95	0.00	N.A.	58.67	0.00	130.91	20.21	9,859.58	2,174.97	1.64616	0.28323	4.2424
10/26/2018	523,975	99.77	0.00	N.A.	18.33	0.00	27.73	3.14	960.69	1,585.74	0.26332	0.03701	2.48763
11/15/2018	260,611	39.76	1.06	N.A.	9.28	0.00	11.51	0.00	185.90	11,779.31	0.08458	0	0.8388
1/4/2019	269,754	16.84	1.22	N.A.	18.63	0.00	4.69	0.00	102.81	1,300.21	0.15056	0	0.31052
2/20/2019	111,505	0.00	0.00	N.A.	8.07	0.00	1.82	0.00	37.63	9,292.83	0.0091	0	0.22757
6/10/2019	168,619	13.22	1.05	N.A.	8.78	0.57	5.63	0.41	89.29	745.36	0	0	0.19904
6/12/2019	S.M.	S.M.	S.M.	S.M.	S.M.	S.M.	S.M.	S.M.	S.M.	S.M.	S.M.	S.M.	S.M.
Station WC003													
7/17/2018	215,264	85.90	2.12	10.95	10.82	N.A.	22.90	3.50	1,982.61	696.98	0.20598	0.05215	0.90051
9/17/2018	462,344	54.38	0.00	N.A.	11.88	0.00	24.56	0.00	719.64	978.09	0.27044	0.02388	0.57046
10/26/2018	212,610	30.20	0.00	N.A.	5.85	0.00	11.95	0.33	301.02	817.39	0.10023	0.00546	0.59139
11/15/2018	91,338	9.19	0.00	N.A.	2.55	0.00	3.62	0.00	44.07	4,249.91	0.01711	0	0.23783
1/4/2019	95,118	5.94	0.00	N.A.	5.00	0.00	1.80	0.00	55.90	519.73	0.02047	0	0.12108
2/20/2019	62,594	0.00	0.00	N.A.	3.35	0.00	1.95	0.00	21.41	3,775.12	0.01081	0	0.12059
6/10/2019	69,812	13.00	0.41	N.A.	2.08	0.32	4.09	0.39	182.10	347.83	0	0	0.26569
6/12/2019	78,069	12.39	0.55	N.A.	1.43	0.22	4.60	0.48	173.72	305.84	0.02383	0.00529	0.27714
Station WC004													
7/17/2018	168,229	44.60	1.39	5.13	4.81	N.A.	11.49	1.73	881.56	405.59	0.09008	0.03283	0.69017
9/17/2018	233,020	26.51	0.00	N.A.	4.05	0.00	10.81	0.00	267.74	455.13	0.09356	0.0101	0.24421
10/26/2018	112,317	11.73	0.00	N.A.	2.74	0.00	6.47	0.28	154.73	296.26	0.05386	0.00471	0.81778
11/15/2018	22,932	1.43	0.00	N.A.	0.38	0.00	0.13	0.00	6.04	335.44	0.00707	0.00009	0.05691
1/4/2019	37,096	2.32	0.00	N.A.	1.49	0.00	1.03	0.00	13.24	143.04	0.01271	0	0.06358
2/20/2019	40,782	1.94	0.00	N.A.	1.84	0.00	2.11	0.00	26.16	2,541.56	0.01149	0	0.11531
6/10/2019	57,887	9.11	0.48	N.A.	2.44	0.19	4.28	0.22	38.20	214.31	0.00149	0	0.16286
6/12/2019	58,025	8.04	0.48	N.A.	0.46	0.22	3.83	0.30	40.46	112.12	0.01832	0.00159	0.13117

S.M. = Sampler Malfunction
N.A. = Parameter Not Analyzed

Table 4-7. Average storm pollutant loads (lbs/event), Wheel Creek monitoring, July 2018 – June 2019 (non-detects set to zero)

Station	5-Day BOD	Ammonia	Nitrate	Nitrate + Nitrite	Ortho-phosphate	TKN	Total P	TSS	Chloride	Copper	Lead	Zinc
WC002	122.05	1.22	30.47	21.59	0.19	34.03	4.51	2,345.61	4,042.73	0.36	0.06	1.47
WC003	26.38	0.38	10.95	5.37	0.09	9.43	0.59	435.06	1,461.36	0.08	0.01	0.39
WC004	13.21	0.29	5.13	2.27	0.07	5.02	0.32	178.52	562.93	0.04	0.01	0.29

4.5 SEDIMENT TRANSPORT SAMPLING RESULTS

A summary of suspended sediment transport data for Stations WC002, WC003, and WC004 and suspended sediment transport curves for Stations WC002 and WC003 are presented below. The discharges associated with each sediment sample were approximated from flow rate data recorded at the time when the stage at which the samplers filled, as shown by stage loggers attached to the siphon samplers, was achieved.

During eight sampling events from July 2018 to June 2019, a total of 25 samples were collected at Station WC002 (Table 4-8), 23 samples were collected at Station WC003 (Table 4-9), and 21 samples were collected at Station WC004 (Table 4-10). Note that bottles are numbered in sequence from the lowest to the highest point in the water column. Suspended sediment concentrations ranged from 2.1 to 488 mg/L at Station WC002, 2.2 to 635 mg/L at Station WC003, and 2.6 to 342 mg/L at Station WC004.

Table 4-8. Suspended sediment results at Station WC002, July 2018 – June 2019

Date	Bottle Number	Suspended Sediment (mg/L)	Discharge (cfs)	Date	Bottle Number	Suspended Sediment (mg/L)	Discharge (cfs)
17-Jul-18	1	86.0	1.20	26-Oct-18	2	24.3	7.70
17-Jul-18	2	43.4	9.65	26-Oct-18	3	61.8	N.R.
17-Jul-18	3	345.0	8.69	15-Nov-18	1	2.1	1.20
17-Jul-18	4	205.0	28.71	15-Nov-18	2	16.0	3.94
17-Jul-18	5	488.0	35.22	15-Nov-18	3	24.6	18.93
17-Jul-18	6	340.0	35.22	4-Jan-19	1	7.2	1.69
17-Sep-18	1	88.9	1.78	4-Jan-19	2	21.2	1.22
17-Sep-18	2	163.0	5.08	20-Feb-19	1	11.1	1.40
17-Sep-18	3	291.0	28.99	10-Jun-19	1	106.0	1.03
17-Sep-18	4	234.0	53.25	10-Jun-19	2	17.3	3.77
17-Sep-18	5	247.0	68.13	12-Jun-19	1	41.7	0.96
17-Sep-18	6	352.0	105.35	12-Jun-19	2	41.2	4.69
26-Oct-18	1	58.7	1.27				

N.R. – Corresponding level data from logger and flow rate could not be determined for this sample.

Table 4-9. Suspended sediment results at Station WC003, July 2018 – June 2019

Date	Bottle Number	Suspended Sediment (mg/L)	Discharge (cfs)	Date	Bottle Number	Suspended Sediment (mg/L)	Discharge (cfs)
17-Jul-18	1	287.0	2.87	26-Oct-18	2	76.5	1.63
17-Jul-18	2	254.0	2.17	26-Oct-18	4	63.8	N.R.
17-Jul-18	3	356.0	8.23	15-Nov-18	1	4.2	0.34
17-Jul-18	4	92.2	7.21	15-Nov-18	2	11.5	1.57
17-Jul-18	5	635.0	N.R.	4-Jan-19	1	2.2	0.25
17-Sep-18	1	183.0	2.04	20-Feb-19	1	5.8	0.27
17-Sep-18	2	163.0	2.54	20-Feb-19	2	12.3	1.35
17-Sep-18	3	408.0	6.86	10-Jun-19	1	83.4	0.37
17-Sep-18	4	79.8	9.88	10-Jun-19	2	242.0	1.24
17-Sep-18	5	277.0	10.53	12-Jun-19	1	76.4	0.34
17-Sep-18	6	171.0	N.R.	12-Jun-19	2	77.6	1.40
26-Oct-18	1	96.6	0.77				

N.R. – Corresponding level data from logger and flow rate could not be determined for this sample.

Table 4-10. Suspended sediment results at Station WC004, July 2018 – June 2019

Date	Bottle Number	Suspended Sediment (mg/L)	Discharge	Date	Bottle Number	Suspended Sediment (mg/L)	Discharge
17-Jul-18	1	231.0	5.39	17-Sep-18	6	82.6	N.R.
17-Jul-18	2	111.0	7.99	26-Oct-18	1	9.8	N.R.
17-Jul-18	3	164.0	N.R.	26-Oct-18	2	14.1	N.R.
17-Jul-18	4	245.0	N.R.	26-Oct-18	3	8.6	N.R.
17-Jul-18	5	342.0	N.R.	15-Nov-18	1	4.1	N.R.
17-Jul-18	6	75.4	N.R.	15-Nov-18	3	22.3	N.R.
17-Sep-18	1	5.9	5.32	4-Jan-19	1	2.6	0.18
17-Sep-18	2	98.6	5.12	20-Feb-19	1	19.0	N.R.
17-Sep-18	3	115.0	N.R.	10-Jun-19	1	110.0	0.20
17-Sep-18	4	62.7	N.R.	12-Jun-19	1	29.5	N.R.
17-Sep-18	5	78.8	N.R.				

N.R. – Corresponding level data from logger and flow rate could not be determined for this sample.

Sediment transport curves were created for each station using concentrations of suspended sediment in samples and corresponding flow rate values for storms monitored from July 2018 through June 2019. No sediment transport curve was prepared for WC004 because only six bottles could be correlated to level data recorded by the onboard level logger in this siphon sampler and assigned a flow rate value. Additionally, the level logger at this station was found to be incorrectly positioned within the siphon sampler, resulting in recording erroneous data throughout most of the stormflows. The logger has been correctly positioned for the next reporting year. Results at Station WC002 showed a moderate correlation between discharge and suspended sediment concentration (r^2 = 0.54; Figure 4-16). Average instantaneous discharges for each sample were approximately the same as those reported in the previous year. The sediment transport curve prepared for Station WC003 showed a moderate correlation between discharge and suspended sediment concentration (r^2 = 0.46; Figure 4-17). The sediment concentration correlation at Station WC003 was similar to that reported last year, with slightly lower concentrations per discharge noted.

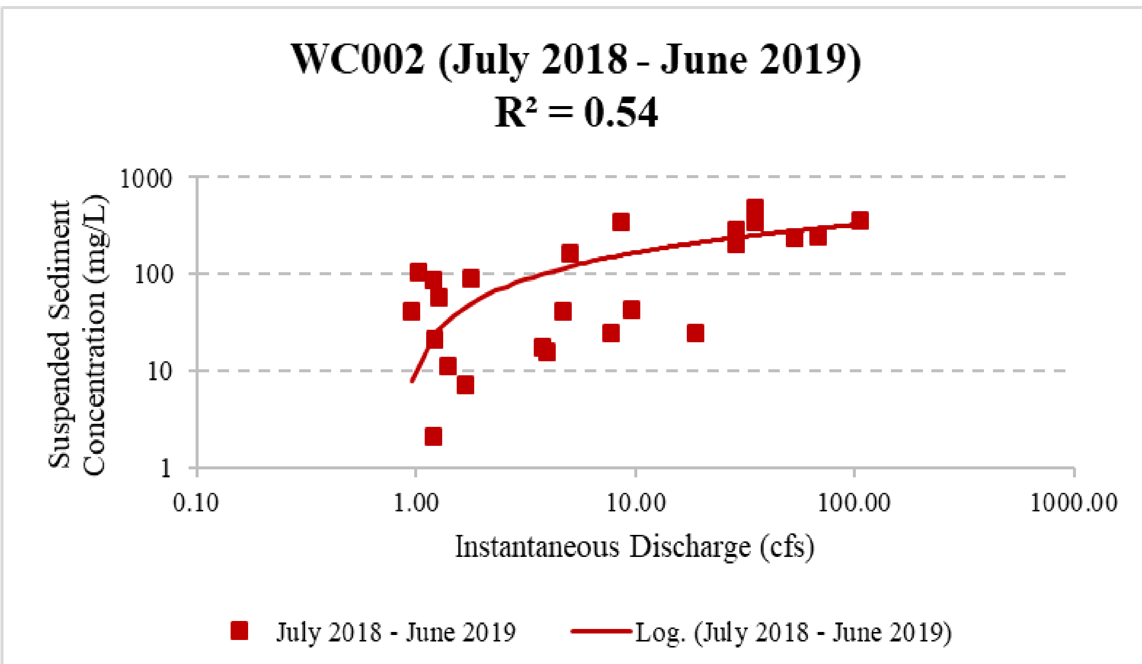

Figure 4-16. Suspended sediment curve for Wheel Creek Station 002 (July 2018 – June 2019)

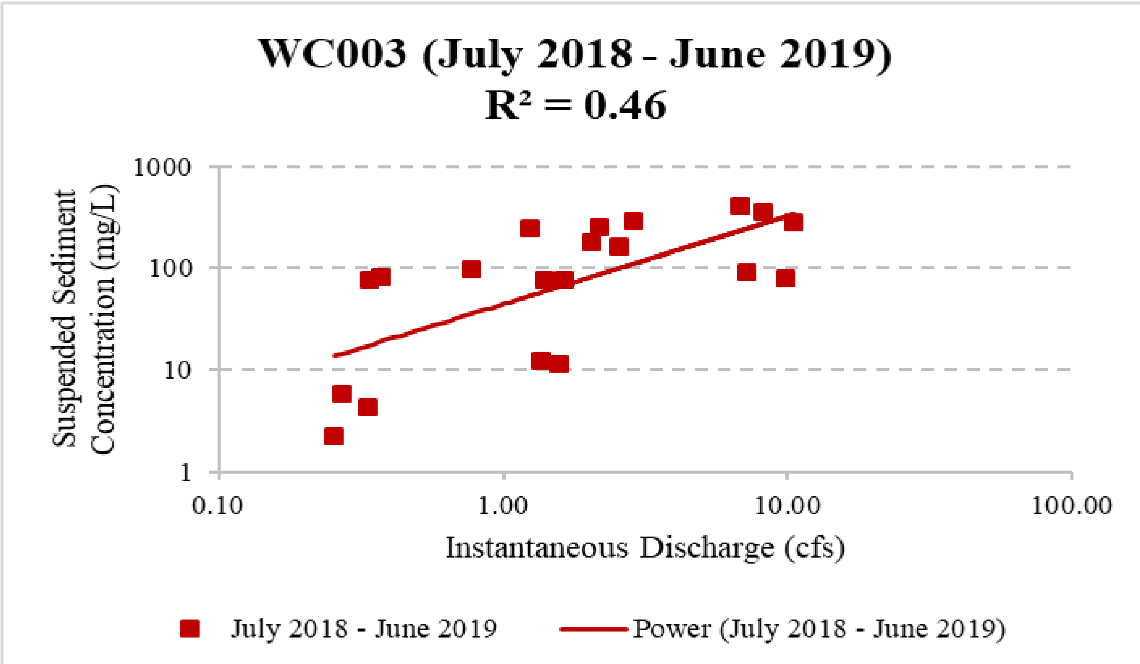

Figure 4-17. Suspended sediment curve for Wheel Creek Station 003 (July 2018 – June 2019)

The arithmetic mean of stormflow-associated suspended sediment concentrations, by station, exceeded corresponding average annual EMCs of TSS, suggesting that TSS results underestimate the actual transport of sediment during storms (Figure 4-18).

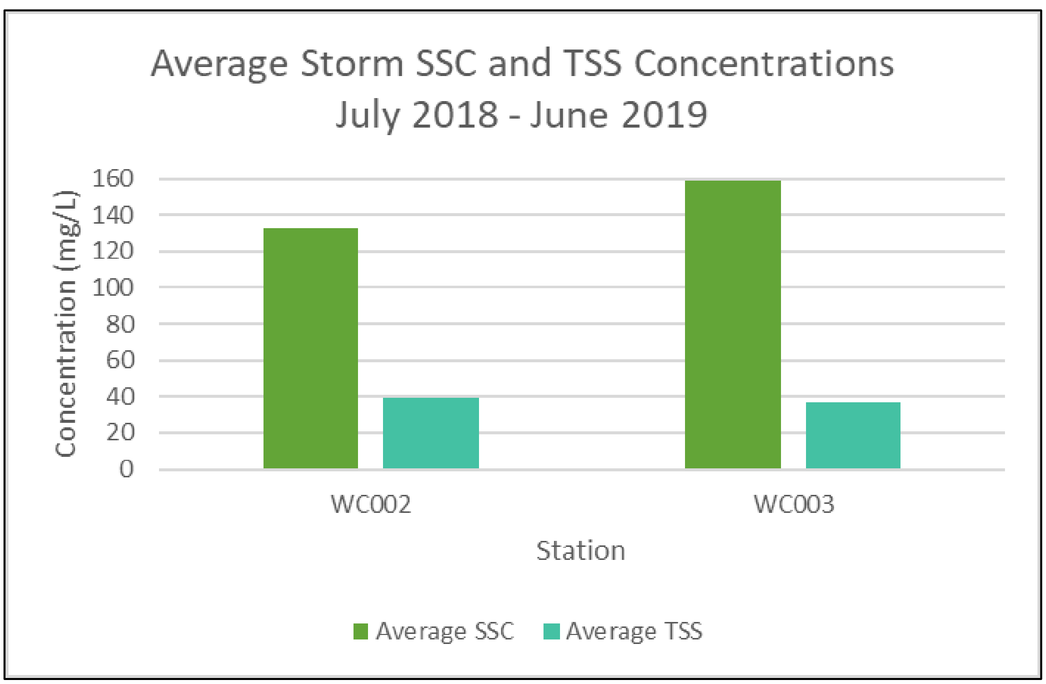

Figure 4-18. Average SSC and TSS concentrations in stormwater runoff (July 2018 – June 2019)

4.6 MONITORING PROBLEMS IDENTIFIED IN 2018-2019

4.6.1 Storm Events

During the July 17-18, 2018 storm event, the area-velocity probe became blocked by debris during high flows at Station WC002. To approximate discharge during the storm event for composite samples, the flow data from Station WC003 were used.

During the October 26-27, 2018 storm event, the bubbler line detached from the sensor at Station WC002. To approximate discharge during the storm event for compositing, field staff used the flow data and hydrograph from Station WC003.

During the November 15-16, 2018 storm event, flow levels were elevated at the time of composite, so the field staff obtained the falling limb grab sample at both Station WC002 and Station WC004.

During the January 4-5, 2019 storm event at Station WC003, the field crew encountered erroneous data throughout the peak and falling limbs due to the bubbler line being blocked by debris. The field crew used the hydrograph and discharge data from Station WC002 to complete the composite.

During the February 20-21, 2019 storm event at Station WC003, the field crew noticed erroneous data during the peak limb due to the bubbler being blocked by debris. The field crew used the hydrograph and discharge data from Station WC002 to complete the composite. At Station WC003, the field crew obtained the falling limb by taking a grab sample due to snow melt.

During the June 10-11, 2019 storm event, the field crew noticed erroneous level data at Station WC003 due to debris interference with the sensor. The field crew used the Station WC002 hydrograph and discharge data to complete the composite for Station WC003.

During the June 12-13, 2019 storm event, Station WC002 failed to sample during the event due to a failed battery. The field crew also encountered erroneous level data at Station WC003 due to the bubbler being blocked by debris. The field crew used the hydrograph and discharge data from Station WC004 to complete the partial composite for the event.

4.6.2 Continuous Stage Logging

The Solinst level loggers at each station were downloaded monthly. Episodes of sensor drift due to presence of sediment after storm flows and leaf debris in the fall have been noted. The level loggers occasionally accumulate sediment in the sensor holes, which needs to be removed. Leaf debris buildup in the channels causes a temporary backwater condition, causing heightened stage and artificially inflated flow rate readings. Adjustments to correct for the drift and leaf buildup were performed to improve the flow record.

In the winter, there were several months when the Solinst level loggers were removed from the stream due to cold weather and risk of damage to sensors from ice buildup. To reduce data gaps, ISCO bubbler flowmeters were installed at each site when the Solinst instruments were temporarily removed. Bubbler flowmeters are less prone to damage due to ice buildup around the sensor.

The August 31, 2018 storm changed the stream channel at the WC002 station, resulting in a change in baseflow stream level. The data from the Solinst level logger from this site were adjusted accordingly for the remainder of the year to account for this shift in baseflow stream height.

To account for data gaps, the following protocols were used to complete the stage records. All data from the Solinst level loggers were aggregated, and anomalous data encountered during data offloads and logger swapping were manually interpolated with the surrounding stage data. The level logger data were shifted to match observed actual staff gauge readings, and linear drift corrections were applied to correct periods of sensor drift. ISCO flowmeter data were also shifted to match staff gauge observations and Solinst level logger data; the ISCO level data were used when Solinst level loggers were offline. If no Solinst or ISCO level data were recorded, data gaps were filled by using stage data downloaded from the USGS “0158175320 WHEEL CREEK NEAR ABINGDON” gauging station. The USGS data were shifted temporally to match peaks in each station’s level data, and a predictive model was developed using all valid overlapping data for each station. The modeled data underwent quality control and were shifted to match observations bounding the periods of missing level data. All missing data were estimated from these models of USGS data.

4.7 COMPARISON OF PRE- AND POST-RESTORATION CONDITIONS

4.7.1 Comparison of Pollutant Ratios Between Stations WC002 and WC003

For this evaluation, a comparison of the ratios (in percent) of average pollutant concentrations and annual loads between Station WC003 and Station WC002 was employed to determine the benefit, in terms of pollution reduction, of restoration projects in the mainstem and in the middle branch between Station WC003 and Station WC002.

Total Annual Load

For the purpose of comparison, samples collected in 2010 and 2011 were treated as fully “pre-restoration” and those collected in FY2017-2019 were treated as fully “post-restoration.” If the ratio of pollutant load between the upstream station (WC003) and downstream station (WC002) during post-restoration conditions was less than the baseline ratio during pre-restoration conditions, then it may be concluded that the restoration projects reduced loading between the stations. Total loads and ratios are presented in Table 4-11. For comparison, intermediate post-restoration results using data collected in 2014, when no construction was in progress in the study area, are provided as in Jones et al. (2016).

In terms of total annual load, the ratios of the downstream station (WC002) to the upstream station (WC003) for nutrients were greater during post-restoration conditions than during pre-restoration conditions. Lead, copper, zinc, BOD, and TSS ratios were lower during the post-restoration phase, indicating that the restoration between the stations succeeded in reducing pollutant loads for these pollutants.

Storm EMCs

The ratios of average EMCs of pollutants during storm events captured during pre-restoration conditions were compared to the ratios of average EMCs for storms captured during post-restoration conditions. The average EMCs during these periods, and comparisons between periods, are provided in Table 4-12.

For all pollutants except ammonia, the average storm EMCs at the downstream station exceeded those at the upstream during pre-restoration; however, none of the differences were significant. After completion of restoration projects, the average storm EMCs of copper, zinc, and ammonia at the downstream station were less than at the upstream. Total nitrogen, TSS, BOD, and lead at the downstream station, conversely, were substantially higher than at the upstream station, though the differences were not significant. The change in ratios suggests that the restoration in the contributing subwatersheds has reduced pollutant concentrations at Station WC002 under stormflow conditions except for total nitrogen, TSS, BOD, and lead.

Baseflow MCs

The ratios of average baseflow MCs of pollutants during pre-restoration conditions were compared to the ratios of average baseflow MCs during post-restoration conditions. The average MCs during these periods, and comparisons between periods, are provided in Table 4-13.

During pre-restoration phase baseflow conditions, total phosphorus, TSS, ammonia, copper, and zinc concentrations at the upstream station exceeded those at the downstream station, with TSS and zinc significant. Concentrations of BOD and total nitrogen were higher at the downstream station. After restoration, only TSS, BOD, copper, and zinc showed improvement in terms of lowering ratios between the upstream and downstream stations, with zinc showing a significant decrease. For the remaining parameters, concentrations at the downstream station became greater in relation to the upstream station, with total nitrogen showing a significant increase.

Table 4-11. Comparison of Pre-Restoration and Post-Restoration Total Annual Loads

Phase	Total Load (lbs) WC002	Total Load (lbs) WC003	Ratio
Total Nitrogen			
Pre-Restoration (2010-2011)	7,258	1,905	73.8%
Post-Restoration (2014)	6,958	1,307	81.2%
Post-Restoration (FY 2017-19)	14,662	3,114	78.8%
Total Phosphorus			
Pre-Restoration (2010-2011)	281.8	73.9	73.8%
Post-Restoration (2014)	171.5	33.4	80.5%
Post-Restoration (FY 2017-19)	654.7	138.4	78.9%
TSS			
Pre-Restoration (2010-2011)	126,203	26,438	79.1%
Post-Restoration (2014)	67,237	12,413	81.5%
Post-Restoration (FY 2017-19)	191,063	57,128	70.1%
Ammonia			
Pre-Restoration (2010-2011)	72.4	32.1	55.7%
Post-Restoration (2014)	83.3	32.7	60.7%
Post-Restoration (FY 2017-19)	561.3	162.3	71.1%
BOD			
Pre-Restoration (2010-2011)	4,914	1,030	79.0%
Post-Restoration (2014)	14,168	2,918	79.4%
Post-Restoration (FY 2017-19)	31,350	8,716	72.2%
Copper			
Pre-Restoration (2010-2011)	19.2	4.9	74.3%
Post-Restoration (2014)	16.8	3.3	80.3%
Post-Restoration (FY 2017-19)	33.1	12.3	62.8%
Lead			
Pre-Restoration (2010-2011)	4.4	0.2	96.3%
Post-Restoration (2014)	3.3	0.5	84.1%
Post-Restoration (FY 2017-19)	4.7	1.5	68.4%
Zinc			
Pre-Restoration (2010-2011)	137.9	43.7	68.3%
Post-Restoration (2014)	101.1	24.2	76.1%
Post-Restoration (FY 2017-19)	247.5	84.9	65.7%

Table 4-12. Pre- and Post-Restoration Average Storm EMCs (shaded cells indicate significant results)				
Pollutant (mg/L)	**Station**		**Ratio**	**t test p-value (two-tailed)**
	WC002	**WC003**		
Pre-Restoration Conditions				
Total N	1.50	1.44	4%	0.60
Total P	0.104	0.073	30%	0.17
TSS	46.84	28.54	39%	0.13
Ammonia	0.017	0.030	-72%	0.48
BOD	2.400	1.585	34%	0.12
Copper	0.008	0.006	27%	0.17
Lead	0.479	0.000	100%	0.33
Zinc	0.043	0.038	11%	0.56
Post-Restoration Conditions				
Total N	1.56	1.21	22%	0.10
Total P	0.101	0.095	6%	0.61
TSS	46.26	34.60	25%	0.19
Ammonia	0.071	0.087	-23%	0.79
BOD	6.805	5.186	24%	0.09
Copper	0.008	0.008	-6%	0.97
Lead	0.0013	0.0010	24%	0.30
Zinc	0.037	0.037	-1%	0.75
Note: For all pollutants, α = 0.05				

Table 4-13. Pre- and Post-Restoration Average Baseflow MCs (shaded cells indicate significant results)				
Pollutant (mg/L)	**Station**		**Ratio**	**t test p-value (two-tailed)**
	WC002	**WC003**		
Pre-Restoration Conditions				
Total N	2.14	1.88	12%	0.22
Total P	0.006	0.040	-617%	0.28
TSS	1.38	3.36	-144%	0.04
Ammonia	0.016	0.030	-86%	0.19
BOD	0.900	0.387	57%	0.25
Copper	0.001	0.002	-55%	0.23
Lead	0.0003	0.0003	0%	N/A
Zinc	0.017	0.021	-25%	0.01
Post-Restoration Conditions				
Total N	2.15	1.44	33%	0.001
Total P	0.046	0.011	76%	0.32
TSS	2.67	5.09	-91%	0.59
Ammonia	0.056	0.045	18%	0.43
BOD	2.421	2.726	-13%	0.96
Copper	0.0002	0.0003	-60%	0.25
Lead	0.00023	0.00003	89%	0.27
Zinc	0.019	0.032	-67%	0.0002
Note: For all pollutants, α = 0.05 N/A = not applicable				

4.7.2 Subwatershed-level Evaluation of Pollutant Removal Efficiency

For this evaluation, average storm EMCs and baseflow MCs calculated during pre-restoration conditions were compared to those calculated during post-restoration conditions at each of the three monitoring stations to compute efficiency. The pollutant removal efficiency is a straightforward method to determine the net overall benefit of restoration projects in the contributing subwatershed to each station.

Storm EMCs

The average storm EMCs of pollutants during storm events captured during pre-restoration conditions and post-restoration conditions at each station are provided in Table 4-14.

Table 4-14. Pre- and Post-Restoration Average Storm EMCs (shaded cells indicate significant results)

Pollutant (mg/L)	Phase: Pre-Restoration	Phase: Post-Restoration	Percent Efficiency	t test p-value (two-tailed)
Station WC002				
Total N	1.50	1.49	1%	0.97
Total P	0.104	0.092	12%	0.68
TSS	46.84	46.07	2%	0.96
Ammonia	0.017	0.077	-346%	0.02
BOD	2.400	6.256	-161%	0.07
Copper	0.0079	0.0078	0.5%	0.99
Lead	0.479	0.001	100%	0.33
Zinc	0.043	0.041	4%	0.82
Station WC003				
Total N	1.44	1.18	19%	0.19
Total P	0.073	0.062	14%	0.68
TSS	28.54	34.03	-19%	0.64
Ammonia	0.030	0.104	-252%	0.04
BOD	1.585	4.535	-186%	0.04
Copper	0.006	0.008	-37%	0.38
Lead	0.000	0.001	N/A	0.002
Zinc	0.038	0.040	-4%	0.82
Station WC004				
Total N	1.55	1.29	16%	0.09
Total P	0.068	0.069	-1%	0.95
TSS	18.42	27.76	-51%	0.05
Ammonia	0.093	0.064	32%	0.22
BOD	2.536	4.016	-58%	0.04
Copper	0.007	0.009	-23%	0.14
Lead	0.001	0.001	-30%	0.40
Zinc	0.043	0.042	3%	0.83

Note: For all pollutants, $\alpha = 0.05$
N/A = not applicable

At Station WC002, EMCs of all parameters except ammonia and BOD were reduced from pre-restoration conditions. The reduction in lead was effectively 100% and the reduction in total phosphorus was 12%, whereas the reductions in total nitrogen, TSS, copper, and zinc were much lower at 1%, 2%, 0.5%, and 4%, respectively. Ammonia and BOD increased dramatically, by 346% and 161% respectively, with the increase in ammonia being significant.

At Station WC003, stormflow total nitrogen and total phosphorus decreased between pre-restoration and post-restoration conditions by 19% and 14%, respectively. Ammonia and BOD increased dramatically between pre- and post-restoration phases, with both significant. Copper, zinc, and TSS increased by 37%, 4%, and 19%, respectively.

At Station WC004, zinc, total nitrogen, and ammonia decreased between pre-restoration and post-restoration conditions, by 3%, 16%, and 32%, respectively. Copper, lead, BOD, phosphorus, and TSS increased after completion of restoration activities, with BOD and TSS showing significant increases.

Baseflow MCs

The average baseflow MCs of pollutants during pre-restoration conditions and post-restoration conditions at each station are provided in Table 4-15.

At Station WC002 only baseflow copper and lead MCs were reduced after completion of restoration projects in the contributing subwatershed. The remaining parameters increased between pre-restoration and post-restoration by between 3% for total nitrogen and over 11 times for total phosphorus. Baseflow concentrations of TSS, ammonia, and BOD approximately doubled or quadrupled.

At Station WC003, baseflow data show the restoration projects in the contributing subwatershed reduced pollutants by efficiencies ranging from 27% for total nitrogen to 89% for lead. As has been the case elsewhere and under both flow regimes, BOD dramatically increased, though not significantly. Ammonia and zinc increased by 71% and 67%, respectively, with zinc significant.

At Station WC004, baseflow efficiency results were the least ambiguous, with six of eight parameters reduced between pre-restoration conditions and post-restoration, with significant reductions seen for copper and zinc. Only TSS (298%) and BOD (157%) were greater during post-restoration than pre-restoration.

4.8 LONG-TERM TREND ANALYSIS OF WATER CHEMISTRY DATA

The time-series statistical tests performed on baseflow concentration and individual storm EMC data collected showed a significant downward trend for baseflow nitrate plus nitrite at Station WC003 and a significant downward trend for storm flow nitrate plus nitrite and baseflow total phosphorus and copper at Station WC004. Several constituents have significantly increased over time, such as baseflow TSS at Stations WC002 and WC004, storm flow ammonia at Stations WC002 and WC003, storm flow BOD at all stations, baseflow BOD at Stations WC002 and WC003, storm flow copper at Station WC003, storm flow lead at Stations WC003 and WC004, and baseflow zinc

Table 4-15. Pre- and Post-Restoration Average Baseflow MCs (shaded cells indicate significant results)

Pollutant (mg/L)	Phase		Percent Efficiency	t test p-value (two-tailed)
	Pre-Restoration	Post-Restoration		
Station WC002				
Total N	2.14	2.21	-3%	0.78
Total P	0.006	0.070	-1136%	0.35
TSS	1.38	2.40	-74%	0.35
Ammonia	0.016	0.075	-373%	0.07
BOD	0.900	1.959	-118%	0.23
Copper	0.0011	0.0003	70%	0.09
Lead	0.00034	0.00001	97%	0.34
Zinc	0.017	0.021	-23%	0.27
Station WC003				
Total N	1.88	1.38	27%	0.07
Total P	0.040	0.012	70%	0.46
TSS	3.36	1.94	42%	0.21
Ammonia	0.030	0.050	-71%	0.43
BOD	0.387	3.858	-897%	0.18
Copper	0.002	0.001	69%	0.15
Lead	0.00034	0.00004	89%	0.44
Zinc	0.021	0.035	-67%	0.01
Station WC004				
Total N	3.49	3.32	5%	0.52
Total P	0.017	0.004	77%	0.14
TSS	0.66	2.62	-298%	0.18
Ammonia	0.052	0.010	80%	0.06
BOD	0.353	0.907	-157%	0.27
Copper	0.0017	0.0004	79%	0.0002
Lead	0.0002	0.0001	49%	0.45
Zinc	0.037	0.023	38%	0.01

Note: For all pollutants, $\alpha = 0.05$
N/A = not applicable

at Stations WC002 and WC003. Overall, the results were mixed, with only 17 of the 54 EMCs and MCs under all flow conditions at all stations becoming lower over time. A summary of test results, including coefficients and significance, for indicator parameters is presented in Table 4-16.

Table 4-16. Results of Kendall's Tau-b significance tests for indicator parameters (2010-FY2019)

Parameter	WC002		WC003		WC004	
	Storm	Baseflow	Storm	Baseflow	Storm	Baseflow
Nitrate + Nitrite	N.S.	N.S.	N.S.	0.0043 (-)	0.0165 (-)	N.S.
Total Kjeldahl Nitrogen	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
Total Phosphorus	N.S.	N.S.	N.S.	N.S.	N.S.	0.0116 (-)
TSS	N.S.	0.0143 (+)	N.S.	N.S.	N.S.	0.0120 (+)
Ammonia	0.0202 (+)	N.S.	0.0391 (+)	N.S.	N.S.	N.S.
BOD	0.0236 (+)	0.0358 (+)	0.0097 (+)	0.0083 (+)	0.0101 (+)	N.S.
Copper	N.S.	N.S.	0.0236 (+)	N.S.	N.S.	0.0201 (-)
Lead	N.S.	N.S.	0.0108 (+)	N.S.	0.0247 (+)	N.S.
Zinc	N.S.	0.0452 (+)	N.S.	0.0002 (+)	N.S.	N.S.

Positive (+) symbols or orange shading indicate an increasing trend over time; negative (-) symbols or green shading indicate a decreasing trend over time
N.S. = not significant

5.0 CONCLUSIONS

In a cooperative effort, Harford County DPW, Versar, and USGS conducted water chemistry and long-term flow monitoring in the Wheel Creek watershed from July 1, 2018 through June 30, 2019. The monitoring effort included ten baseflow sampling and eight wet weather sampling events with suspended sediment transport sampling. Baseflow and stormflow monitoring consisted of sampling for suspended solids, copper, lead, zinc, BOD, ammonia, nitrate plus nitrite, dissolved nitrate plus nitrite, chloride, orthophosphate, total phosphorous, dissolved total phosphorous, TKN, dissolved TKN, turbidity, hardness, TPH, and *E. coli*. Dissolved parameters and nitrate were discontinued after the July 2018 storm.

5.1 SUMMARY OF MONITORING RESULTS

Federal and State reference values for certain nutrients were exceeded on several occasions, confirming detrimental stream chemistry impacts from development and changes in land use. Total nitrogen, calculated from the sum of nitrate plus nitrite and TKN, was present at concentrations exceeding the EPA reference values (0.69 mg/L) for both baseflow (all detected samples) and stormflow (97.1% of detected samples). For total phosphorus, one result in baseflow samples and 86.2% of the detectible results in stormflow samples were found to be above the corresponding EPA reference concentration (0.03656 mg/L). Chloride in stormflow exceeded the EPA acute criterion (860 mg/L) in 10.1% of samples, while 30.0% of baseflow samples exceeded the chronic criterion for chloride (230 mg/L).

All baseflow samples had detectable amounts of zinc but none exceeded the MDE chronic surface water criterion (120 µg/L). All stormflow samples had detectable concentrations of zinc and two samples had an amount exceeding the MDE acute criterion (120 µg/L). All lead concentrations fell below the MDE acute criterion (65 µg/L) for stormflow and the chronic criterion (2.5 µg/L) for baseflow this monitoring period. Copper concentrations did not exceed the MDE chronic criterion (9 µg/L) in baseflow samples, while 8.7% of stormflow samples exceeded the acute criterion (13 µg/L).

E. coli bacteria concentrations were detected in all baseflow samples at all stations, ranging in concentration from 6.3 to greater than the maximum reporting limit of 2,420 MPN/100ml. *E. coli* concentrations were equal to or greater than the maximum reportable result in 33.3% of stormflow grab samples, up from 27.8% in the 2017-2018 monitoring period. TPH was not detected above the reporting limit in any of the baseflow or stormflow grab samples collected at the monitoring stations.

Average baseflow concentrations of combined nitrate plus nitrite, chloride, lead, and copper were highest at Station WC004 compared to the other two stations downstream. Samples collected at Station WC003 had the highest average concentrations of total phosphorus, TSS, and zinc during baseflow conditions. Station WC002 samples had the highest average concentrations of TKN, BOD, and ammonia at baseflow. Average stormflow EMCs were highest at Station WC004 for zinc. Average EMCs for BOD, ammonia, nitrate plus nitrite, total phosphorus, TSS, chloride, copper, lead, and *E. coli* were highest at Station WC002. At Station WC003, only orthophosphate and TKN were highest of the three stations.

Average stormflow loads were highest at Station WC002 and lowest at Station WC004 for all parameters. Since discharge volume for a given storm increases with distance downstream, maximum load results at Station WC002 are expected.

Suspended sediment transport correlated moderately with discharge at Stations WC002 (r^2 = 0.54) and WC003 (r^2 = 0.46). Correlation of suspended sediment to discharge at Station WC004 could not be determined. As in past monitoring periods, the sediment results have correlated better with discharge at the station having the largest contributing watershed area.

5.2 SUMMARY OF RESTORATION EFFECTIVENESS

Comparisons of pre-restoration and post-restoration pollutant load and concentration data were performed to determine the overall benefit to watershed conditions as a result of the implementation of the several restoration projects. Restoration activity initiated in late summer 2012 and concluded in spring 2017, allowing a post-restoration body of data to be accumulated. Subwatershed-level and total watershed benefits were evaluated by leveraging the placement of monitoring stations in relation to the restoration projects and completion timelines. A summary of findings is provided below.

Time series plots of annual average EMCs and MCs for most parameters show a potential downward trend in long-term concentration that can be associated with completion of restoration projects in the watershed. Only nitrate plus nitrite under storm and baseflow conditions appears to trend gradually downward since approximately 2014, coinciding with the completion of most of the restoration projects. Storm EMCs for total phosphorus, TSS, copper, BOD, and TKN show signs of gradually increasing trend until FY2017 before abruptly falling in FY2018, which also coincides with the timeline for most of the restoration projects during 2015-2017. Annual average EMCs and MCs for zinc showed a steady increase through FY2018 but have leveled off in FY2019, and only the annual baseflow MC for ammonia at Station WC002 showed a drastic increase in FY2019 from years past.

Comparing ratios of average concentrations and loads at Stations WC003 and WC002, determined first under pre-restoration conditions and then under post-restoration conditions, produced mixed results. Comparisons of load ratios identified only BOD, TSS, lead, zinc, and copper as being reduced by restoration. Concentration ratios suggest that the restoration in the contributing subwatersheds has reduced concentrations of total phosphorus, TSS, BOD, copper, lead, and zinc at Station WC002 under stormflow conditions. Considering baseflow mean concentrations, only BOD, copper, and zinc showed improvement in terms of lowering percentage differences between the upstream and downstream stations.

Directly comparing post-restoration concentrations (both storm and baseflow) to pre-restoration concentrations showed the following: At Station WC002, EMCs of total nitrogen, total phosphorus, TSS, lead, and zinc were reduced from pre-restoration conditions. At Station WC003, stormflow total phosphorus and total nitrogen decreased between pre-restoration and post-restoration conditions. At Station WC004, zinc, total nitrogen, and ammonia decreased between pre-restoration and post-restoration conditions. At Station WC002 only baseflow copper and lead MCs were reduced after completion of restoration projects in the contributing subwatershed. At Station WC003, baseflow data show the restoration projects in the contributing subwatershed reduced total nitrogen, total phosphorus, TSS, copper, and lead. At Station WC004, baseflow efficiency results were the least ambiguous, with six of eight parameters reduced between pre-restoration conditions and post-restoration.

A summary of the results of tests of restoration effectiveness is provided in Table 5-1.

Table 5-1. Results of tests of restoration effectiveness (bullets indicate pollutant reduction between post- and pre-restoration conditions)

	Target Sub-watershed	Parameter							
		BOD	Ammonia	Total P	TSS	Total N	Copper	Lead	Zinc
Ratio Loads	WC002 below WC003	•			•		•	•	•
Ratio EMC	WC002 below WC003	•		•	•		•	•	•
Ratio MC	WC002 below WC003	•					•		•
Before After EMC	WC002			•	•	•	•	•	
Before After EMC	WC003			•		•			•
Before After EMC	WC004		•			•			•
Before After MC	WC002						•	•	
Before After MC	WC003			•	•	•	•	•	
Before After MC	WC004		•	•		•	•	•	•

The time-series statistical test performed on baseflow concentration and individual storm EMC data collected showed a significant downward trend for baseflow nitrate plus nitrite at Station WC003 and a significant downward trend for storm flow nitrate plus nitrite and baseflow total phosphorus and copper at Station WC004. Several constituents have significantly increased over time, such as baseflow TSS at Stations WC002 and WC004, storm flow ammonia at Stations WC002 and WC003, storm flow BOD at all stations and baseflow BOD at Stations WC002 and WC003, storm flow copper at Station WC003, storm flow lead at Stations WC003 and WC004, and baseflow zinc at Stations WC002 and WC003. Overall, the results were mixed, with only 17 of the 54 EMCs and MCs under all flow conditions at all stations becoming lower over time.

Concentration data show decreases in average annual concentrations of several parameters during the current monitoring period compared to the previous monitoring period (FY2018), which may indicate the continuing of lower trending concentrations as a result of implementation of restoration projects. Results of comparisons of post-restoration to pre-restoration concentrations show that effectiveness was broadest at Station WC004, followed by Stations WC003 and WC002, and mostly reflected in baseflow conditions. When comparing ratios of concentrations at Stations WC002 and WC003 to isolate restoration work in contributing watersheds between the two stations, concentrations in storm runoff have been reduced for nine of 16 parameters. The results of analysis of ratios of loads show benefits in five of eight parameters, with the addition of the lowering of the zinc ratio in FY2019. Given that pollutant load is highly dependent on discharge volume, the variability in storm events that are monitored may increase the variability of load data and complicate the determination of load reduction benefit. The change in contractor laboratory, and consequential change in reporting limits, may also affect the determination of restoration benefits when using water chemistry indicators.

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APPENDIX A

STORM EVENT SUMMARY REPORTS

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WHEEL CREEK STORM MONITORING SUMMARY REPORT

JULY 17-18, 2018

INTRODUCTION

Versar field staff traveled to the site on July 17 to deploy siphon samplers and program the Sigma automated samplers to sample the event. Rainfall initiated at approximately 11:25 a.m. the morning of Tuesday, July 17. At the Wheel Creek Rain Gauge Station, 1.78 inches of rain was recorded for the duration of the storm.

On the afternoon of July 17, field staff collected grab water samples to be tested for TPH and *E. coli* at all three stations that coincided with the rising limb of the storm. The *E. coli* samples were submitted to Enviro-Chem Laboratories for analysis shortly after collection.

Field staff traveled to the sites on July 18 to composite automated and suspended sediment concentration samples (SSC). Siphon samples were submitted to the laboratory for analysis of SSC on July 18. Composite samples, including TPH, were transported to the Harford County Government Department of Public Works Water and Sewer Laboratories on July 18 for analysis.

The following issue occurred during the July 17-18 storm event:

During the storm event, the area-velocity flow sensor at Station WC002 failed due to debris blocking the sensor during the peak limb. Field staff used the hydrograph for Station WC003 to approximate discharge during the storm event for composite samples.

RESULTS

Hydrographs for the July 17-18 storm are presented in Figures A-1 through A-3 below. Laboratory analytical and field water quality results for the storm are shown in Tables A-1 through A-4. Rainfall and flow statistics for the July 17-18 event are shown in Table A-5.

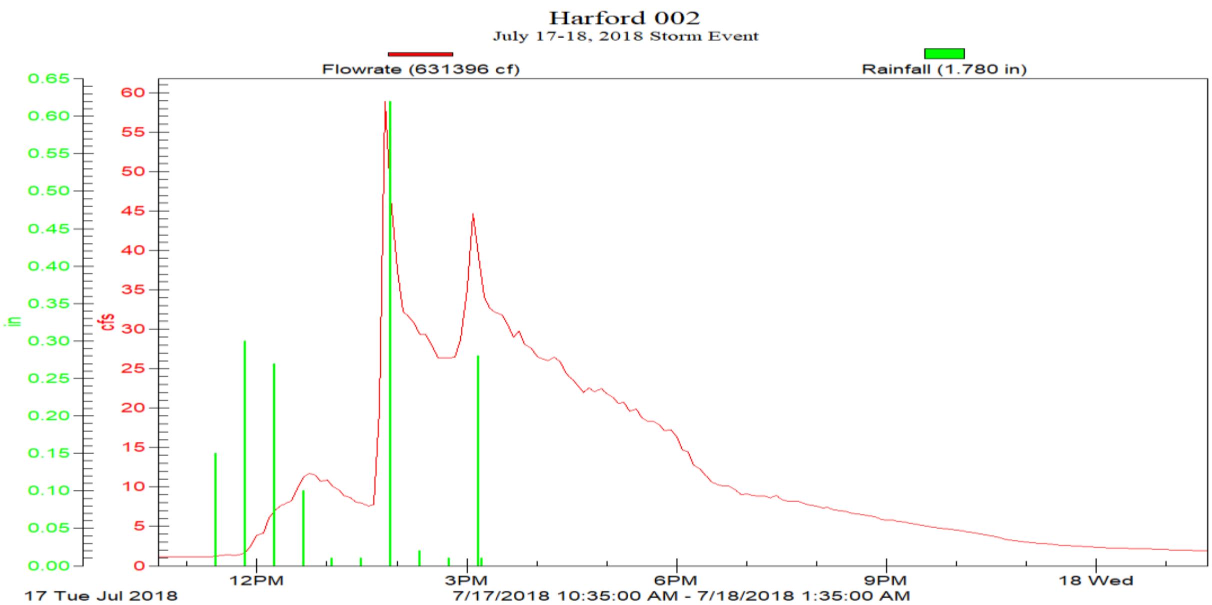

Figure A-1. Hydrograph at Station WC002 for July 17-18, 2018 storm. Rainfall data source: Wheel Creek Rain Gauge Station

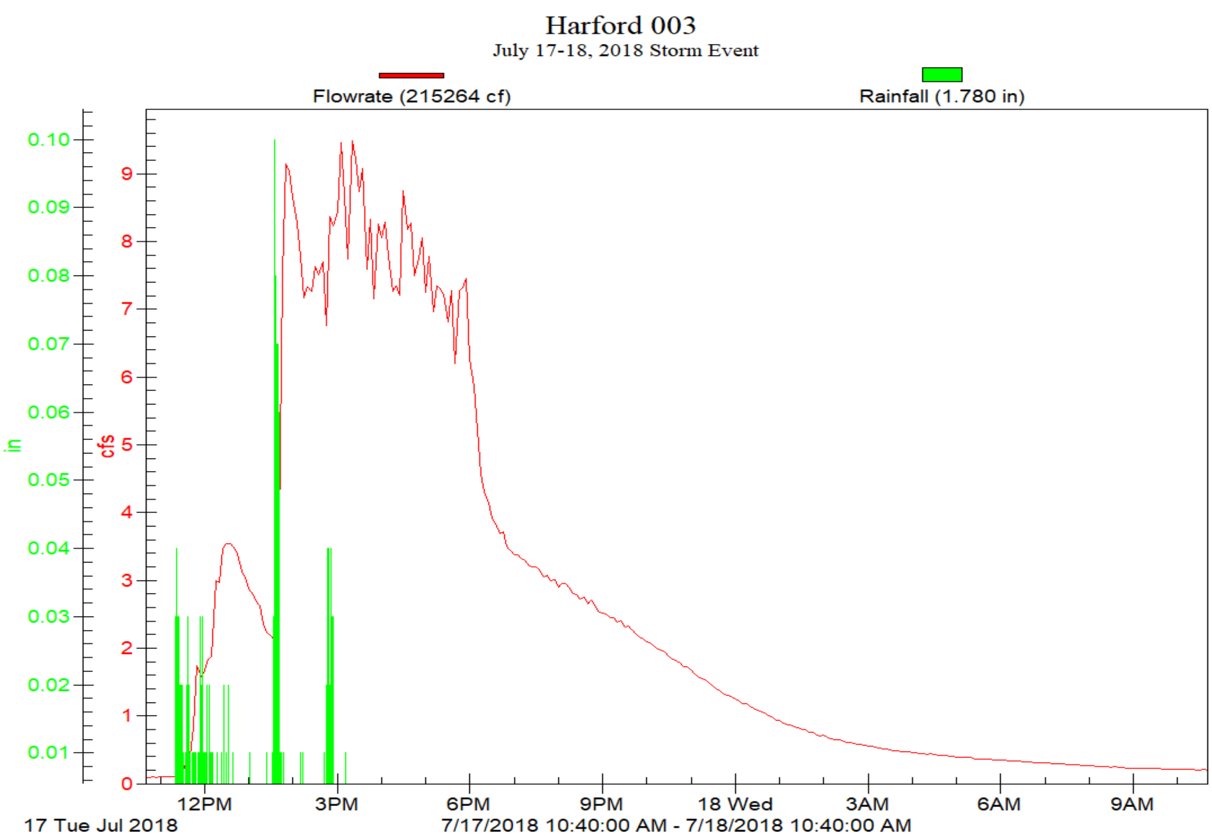

Figure A-2. Hydrograph at Station WC003 for July 17-18, 2018 storm. Rainfall data source: Wheel Creek Rain Gauge Station

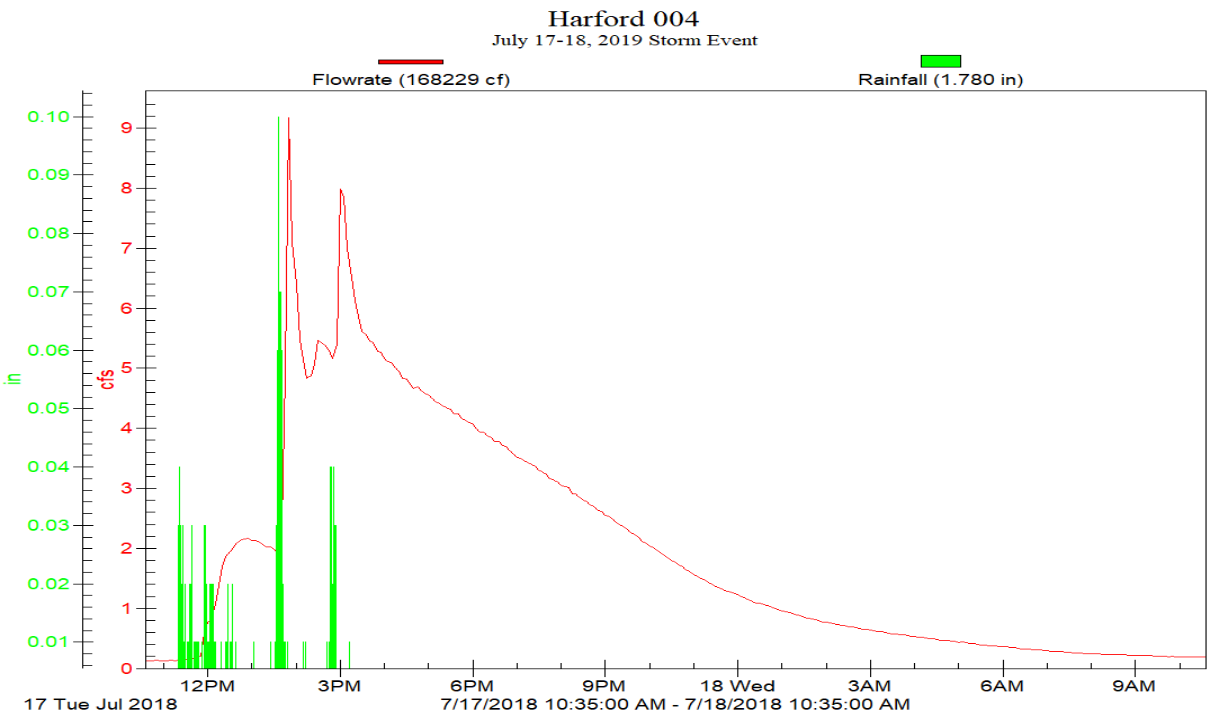

Figure A-3. Hydrograph at Station WC004 for July 17-18, 2018 storm. Rainfall data source: Wheel Creek Rain Gauge Station

Table A-1. Analytical results – Wheel Creek automated sampling, Rising Limb

Constituent	18-Jul-2018		
	Station WC002 (mg/L)	Station WC003 (mg/L)	Station WC004 (mg/L)
5-Day BOD	8.79	9.15	9.27
Nitrate Nitrogen	1.1	1.1	0.7
Nitrate-Nitrite Nitrogen	1.1	1.2	0.67
Orthophosphate Phosphorus	0.011	0.012	0.012
Solids (Suspended)	214	344	364
Copper	0.0186	0.0361	0.0483
Lead	0.0041	0.0097	0.0176
Zinc	0.11	0.164	0.265
Ammonia Nitrogen	0.13	0.22	0.14
Kjeldahl Nitrogen (Total)	2.1	3.5	2.3
Total Phosphorus	0.33	0.71	0.75
Hardness	99.7	115	81.7
Chloride	79.2	95.8	78.1
pH	7.05	7.08	7.12

Table A-2. Analytical results – Wheel Creek automated sampling, Peak Limb

Constituent	18-Jul-2018		
	Station WC002 (mg/L)	Station WC003 (mg/L)	Station WC004 (mg/L)
5-Day BOD	6.42	5.94	3.56
Nitrate Nitrogen	0.76	0.8	0.47
Nitrate-Nitrite Nitrogen	0.72	0.76	0.43
Orthophosphate Phosphorus	0.021	0.016	0.018
Solids (Suspended)	148	115	29
Copper	0.0121	0.0144	<0.040
Lead	0.0026	0.0029	<0.003
Zinc	0.0459	0.0491	0.024
Ammonia Nitrogen	0.15	0.16	0.11
Kjeldahl Nitrogen (Total)	1.5	1.4	0.87
Total Phosphorus	0.22	0.18	0.055
Hardness	32	42.3	21.8
Chloride	26.5	37	28
pH	7.21	7.18	7.29

Table A-3. Analytical results – Wheel Creek automated sampling, Falling Limb			
Constituent	**18-Jul-2018**		
	Station WC002 (mg/L)	**Station WC003 (mg/L)**	**Station WC004 (mg/L)**
5-Day BOD	5.71	5.14	2.23
Nitrate Nitrogen	0.6	0.61	0.38
Nitrate-Nitrite Nitrogen	0.58	0.58	0.37
Orthophosphate Phosphorus	0.019	0.012	0.0075
Solids (Suspended)	45	59	10.5
Copper	<0.040	<0.040	<0.040
Lead	<0.003	0.0013	<0.003
Zinc	0.022	0.0277	0.0196
Ammonia Nitrogen	0.094	0.1	0.18
Kjeldahl Nitrogen (Total)	0.82	0.91	0.75
Total Phosphorus	0.069	0.071	<0.05
Hardness	31.9	47.5	29
Chloride	30.2	50.1	35
pH	7.15	7.12	7.15

Table A-4. Analytical Results – Wheel Creek Grab Sampling			
Constituent	**Station WC002**	**Station WC003**	**Station WC004**
July 18, 2018 (Rising)			
TPH (mg/L)	<1.4	<1.4	<1.4
E. coli (MPN/100 ml)	>2420	>2420	>2420
Temp (C)	22.9	22.4	19.5
DO (mg/L)	7.11	8.28	7.03
pH	7.13	7.09	6.67
Sp. Cond. (mS/cm)	0.399	0.458	0.914

Table A-5. Rainfall and flow statistics			
Constituent	**Station WC002**	**Station WC003**	**Station WC004**
Rainfall (in.)	1.78	1.78	1.78
Duration (hrs.)	15	24	24
Intensity (in./hr.)	0.119	0.074	0.074
Discharge (cf.)	631,396	215,264	168,229

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WHEEL CREEK STORM MONITORING SUMMARY REPORT

SEPTEMBER 17-18, 2018

INTRODUCTION

Versar field staff traveled to the site on September 16 to deploy siphon samplers and program the Sigma automated samplers to sample the event. Rainfall initiated at approximately 10:12 a.m. the morning of Monday, September 17. At the Wheel Creek Rain Gauge Station, 2.52 inches of rain was recorded for the duration of the storm.

On the afternoon of September 18, field staff collected grab water samples to be tested for TPH and *E. coli* at all three stations that coincided with the peak limb of the storm. The *E. coli* samples were submitted to Enviro-Chem Laboratories for analysis shortly after collection.

Field staff traveled to the sites on September 19 to composite automated and suspended sediment concentration samples (SSC). Siphon samples were submitted to the laboratory for analysis of SSC on September 19. Composite samples, including TPH, were transported to the Harford County Government Department of Public Works Water and Sewer Laboratories on September 19.

RESULTS

Hydrographs for the September 17-18 storm are presented in Figures A-1 through A-3 below. Laboratory analytical and field water quality results for the storm are shown in Tables A-1 through A-4. Rainfall and flow statistics for the September 17-18 event are shown in Table A-5.

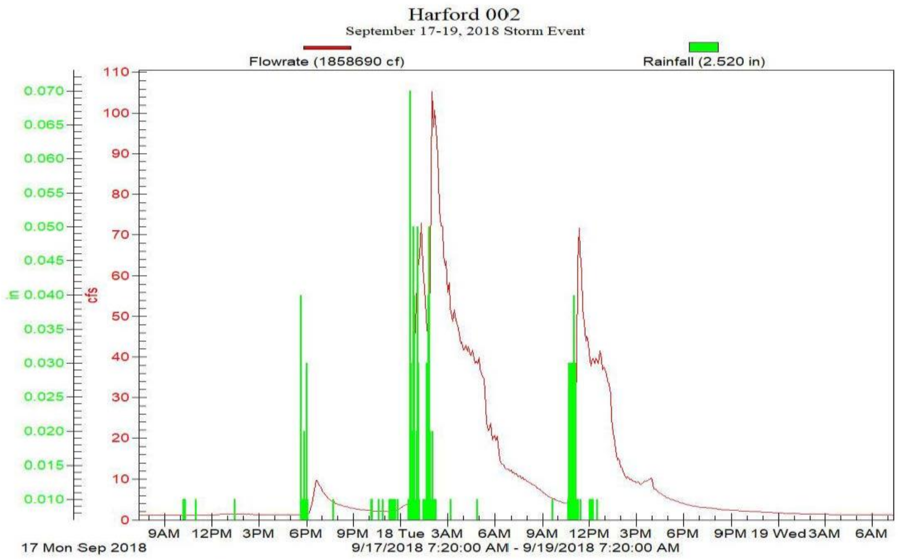

Figure A-1. Hydrograph at Station WC002 for September 17-18, 2018 storm. Rainfall data source: Wheel Creek Rain Gauge Station

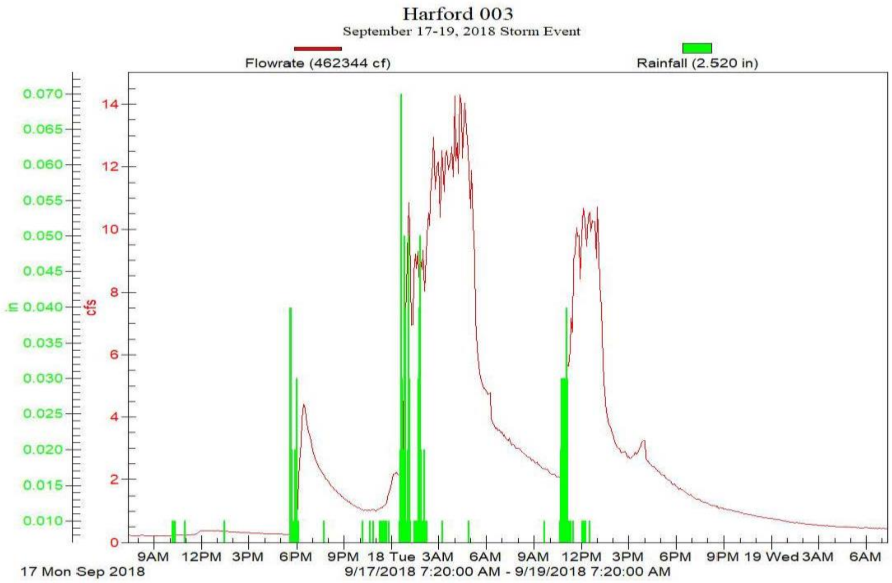

Figure A-2. Hydrograph at Station WC003 for September 17-18, 2018 storm. Rainfall data source: Wheel Creek Rain Gauge Station

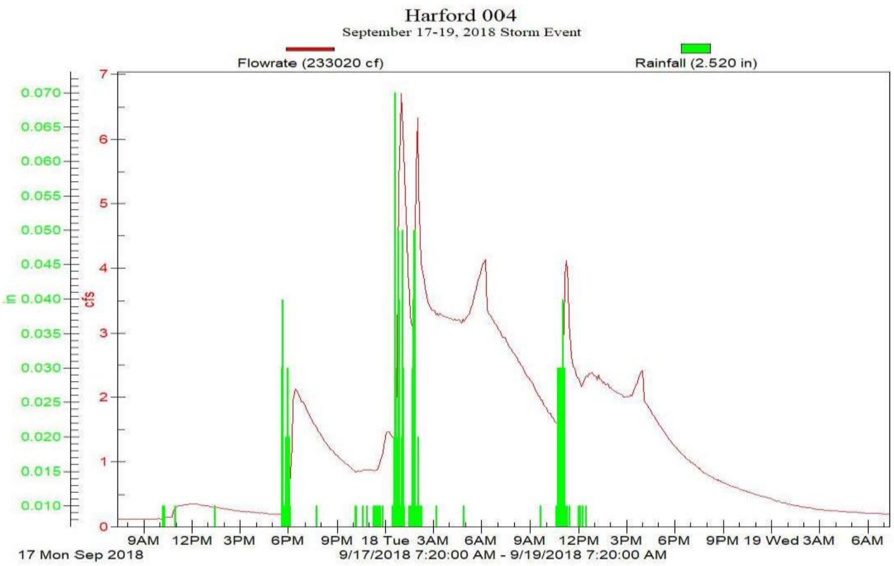

Figure A-3. Hydrograph at Station WC004 for September 17-18, 2018 storm. Rainfall data source: Wheel Creek Rain Gauge Station

Table A-1. Analytical results – Wheel Creek automated sampling, Rising Limb

Constituent	17-18-Sep-2018 Station WC002 (mg/L)	17-18-Sep-2018 Station WC003 (mg/L)	17-18-Sep-2018 Station WC004 (mg/L)
5-Day BOD	3	2	2
Nitrate Nitrogen	NT	NT	NT
Nitrate-Nitrite Nitrogen	0.6	0.4	0.4
Orthophosphate Phosphorus	<0.1	<0.1	<0.1
Solids (Suspended)	20	13	7
Copper	0.007	0.008	0.006
Lead	0.0008	0.0006	0.0004
Zinc	0.033	0.018	0.016
Ammonia Nitrogen	<0.3	<0.3	<0.3
Kjeldahl Nitrogen (Total)	0.7	0.8	0.7
Total Phosphorus	<0.1	<0.1	<0.1
Hardness	67	90	56
Chloride	59.9	71.9	62.2
pH	7.07	7.13	7.15

NT = not tested

Table A-2. Analytical results – Wheel Creek automated sampling, Peak Limb			
Constituent	17-18-Sep-2018		
	Station WC002 (mg/L)	Station WC003 (mg/L)	Station WC004 (mg/L)
5-Day BOD	4	2	2
Nitrate Nitrogen	NT	NT	NT
Nitrate-Nitrite Nitrogen	0.5	0.4	0.2
Orthophosphate Phosphorus	<0.1	<0.1	<0.1
Solids (Suspended)	101	30	26
Copper	0.016	0.01	0.007
Lead	0.003	0.001	0.001
Zinc	0.04	0.021	0.017
Ammonia Nitrogen	<0.3	<0.3	<0.3
Kjeldahl Nitrogen (Total)	1.2	0.9	0.8
Total Phosphorus	0.2	<0.1	<0.1
Hardness	34	36	24
Chloride	15.4	24.2	18
pH	7.23	7.33	7.39
NT = not tested			

Table A-3. Analytical results – Wheel Creek automated sampling, Falling Limb			
Constituent	17-18-Sep-2018		
	Station WC002 (mg/L)	Station WC003 (mg/L)	Station WC004 (mg/L)
5-Day BOD	2	1	1
Nitrate Nitrogen	NT	NT	NT
Nitrate-Nitrite Nitrogen	0.5	0.5	0.4
Orthophosphate Phosphorus	<0.1	<0.1	<0.1
Solids (Suspended)	22	7	6
Copper	0.007	0.007	0.005
Lead	<0.001	<0.001	<0.001
Zinc	0.019	0.014	0.017
Ammonia Nitrogen	<0.3	<0.3	<0.3
Kjeldahl Nitrogen (Total)	0.9	0.6	0.6
Total Phosphorus	0.1	<0.1	<0.1
Hardness	34	62	40
Chloride	21.1	49.7	39.9
pH	7.15	7.19	7.29
NT= not tested			

Table A-4. Analytical Results – Wheel Creek Grab Sampling			
Constituent	**Station WC002**	**Station WC003**	**Station WC004**
September 18, 2018 (Peak)			
TPH (mg/L)	<5	<5	<5
E. coli (MPN/100 ml)	>2420	>2420	>2420
Temp (C)	19.8	20.1	21
DO (mg/L)	8.7	8.49	8.46
pH	7.42	7.26	6.59
Sp. Cond. (mS/cm)	1.54	1.63	1.071

Table A-5. Rainfall and flow statistics			
Constituent	**Station WC002**	**Station WC003**	**Station WC004**
Rainfall (in.)	2.52	2.52	2.52
Duration (hrs.)	48	48	48
Intensity (in./hr.)	0.053	0.053	0.053
Discharge (cf.)	1,858,690	462,344	233,020

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WHEEL CREEK STORM MONITORING SUMMARY REPORT

OCTOBER 26-27, 2018

INTRODUCTION

Versar field staff traveled to the site on October 26 to deploy siphon samplers and program the Sigma automated samplers to sample the event. Rainfall initiated at approximately 7:00 p.m. the night of Friday, October 26. At the Wheel Creek Rain Gauge Station, 1.30 inches of rain was recorded for the duration of the storm.

On the evening of October 26, field staff collected grab water samples to be tested for TPH and *E. coli* at all three stations that coincided with the rising limb of the storm. The *E. coli* samples were submitted to Enviro-Chem Laboratories for analysis shortly after collection.

Field staff traveled to the sites on October 29 to composite automated and suspended sediment concentration samples (SSC). Siphon samples were submitted to the laboratory for analysis of SSC on November 5. Composite samples, including TPH samples were transported to the Harford County Government Department of Public Works Water and Sewer Laboratories on October 29.

The following issue occurred during the October 26-27 storm event:

The ISCO flowmeter bubbler line detached during the storm event at Station WC002 therefore, the hydrograph and proportions of discrete samples from Station WC003 were used for preparation of the composite samples. The ISCO flowmeter bubbler line was reattached for future storm events.

RESULTS

Hydrographs for the October 26-27 storm are presented in Figures A-1 through A-3 below. Laboratory analytical and field water quality results for the October 26-27 storm are shown in Tables A-1 through A-4. Rainfall and flow statistics for the event are shown in Table A-5.

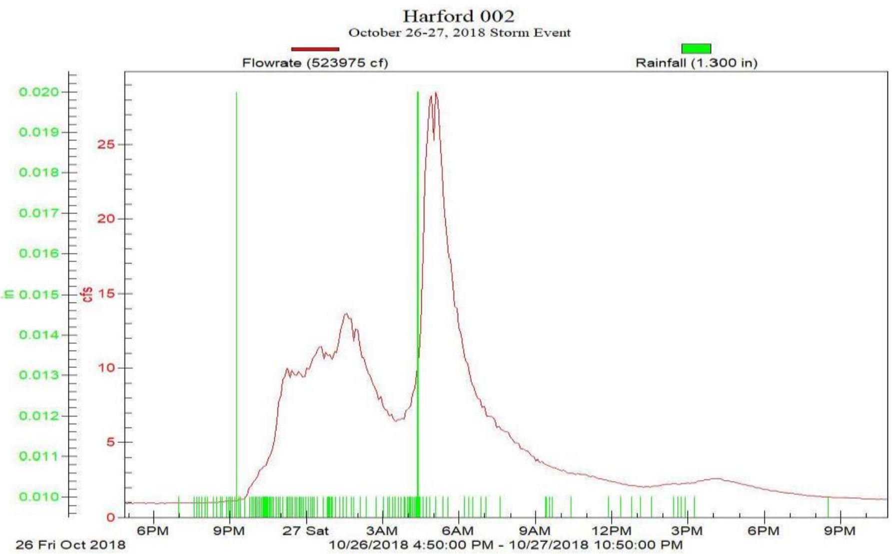

Figure A-1. Hydrograph at Station WC002 for October 26-27, 2018 storm. Rainfall data source: Wheel Creek Rain Gauge Station

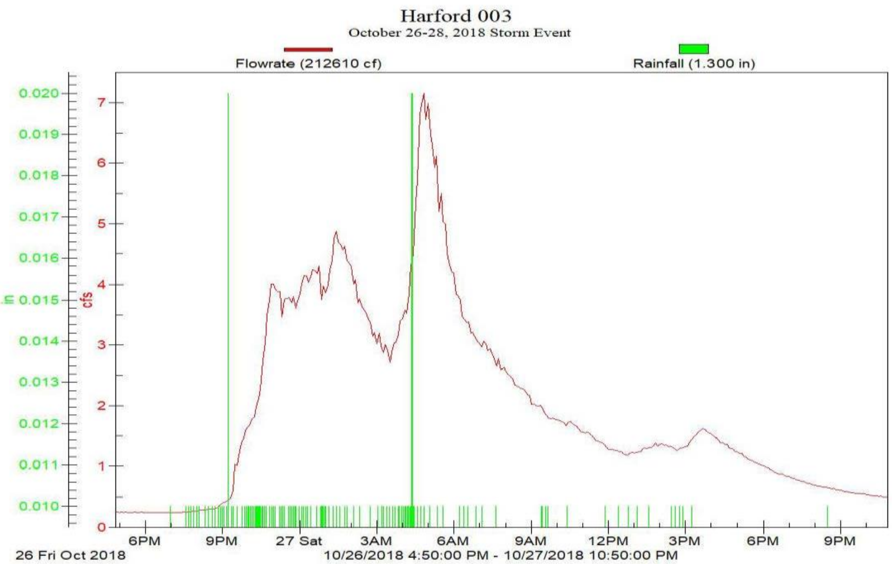

Figure A-2. Hydrograph at Station WC003 for October 26-27, 2018 storm. Rainfall data source: Wheel Creek Rain Gauge Station

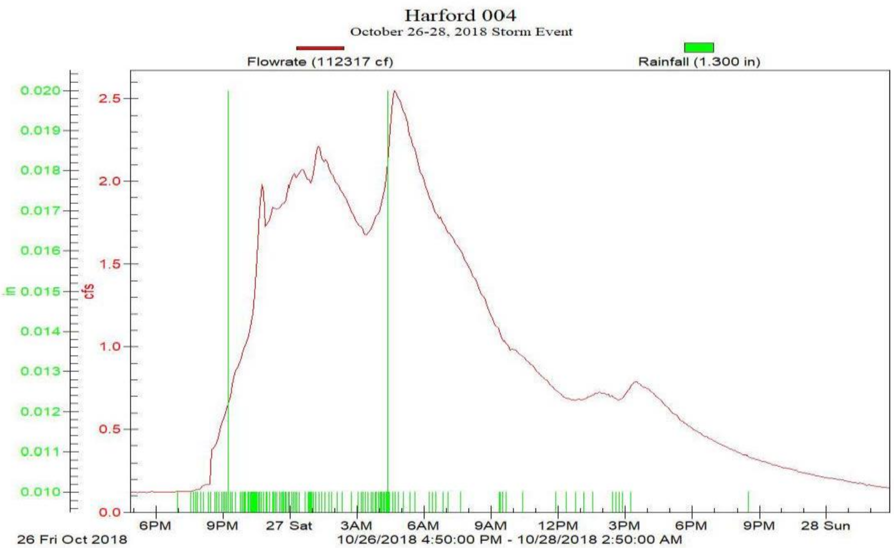

Figure A-3. Hydrograph at Station WC004 for October 26-27, 2018 storm. Rainfall data source: Wheel Creek Rain Gauge Station

Table A-1. Analytical results – Wheel Creek automated sampling, Rising Limb

Constituent	26-27-Oct-2018		
	Station WC002 (mg/L)	Station WC003 (mg/L)	Station WC004 (mg/L)
5-Day BOD	4	5	3
Nitrate Nitrogen	NT	NT	NT
Nitrate-Nitrite Nitrogen	1	0.6	0.5
Orthophosphate Phosphorus	<0.1	<0.1	<0.1
Solids (Suspended)	51	65	45
Copper	0.009	0.013	0.011
Lead	0.002	0.003	0.002
Zinc	0.076	0.095	0.118
Ammonia Nitrogen	<0.3	<0.3	<0.3
Kjeldahl Nitrogen (Total)	1.1	1.3	1.2
Total Phosphorus	0.12	0.18	0.12
Hardness	115	120	60
Chloride	94.3	118	56.8
pH	7.71	8.09	7.73

NT = not tested

Table A-2. Analytical results – Wheel Creek automated sampling, Peak Limb

Constituent	26-27-Oct-2018		
	Station WC002 (mg/L)	Station WC003 (mg/L)	Station WC004 (mg/L)
5-Day BOD	3	2	1
Nitrate Nitrogen	NT	NT	NT
Nitrate-Nitrite Nitrogen	0.4	0.4	0.3
Orthophosphate Phosphorus	<0.1	<0.1	<0.1
Solids (Suspended)	26	18	12
Copper	0.008	0.007	0.006
Lead	0.001	<0.001	<0.001
Zinc	0.08	0.04	0.118
Ammonia Nitrogen	<0.3	<0.3	<0.3
Kjeldahl Nitrogen (Total)	0.8	0.9	0.8
Total Phosphorus	0.1	<0.1	<0.1
Hardness	50	50	<50
Chloride	34	50.6	32.2
pH	7.82	8.12	7.78

NT = not tested

Table A-3. Analytical results – Wheel Creek automated sampling, Falling Limb

Constituent	26-27-Oct-2018		
	Station WC002 (mg/L)	Station WC003 (mg/L)	Station WC004 (mg/L)
5-Day BOD	1	1	1
Nitrate Nitrogen	NT	NT	NT
Nitrate-Nitrite Nitrogen	0.8	0.5	0.5
Orthophosphate Phosphorus	<0.1	<0.1	<0.1
Solids (Suspended)	2	5	3
Copper	0.006	0.005	0.006
Lead	<0.001	<0.001	<0.001
Zinc	0.042	0.018	0.106
Ammonia Nitrogen	<0.3	<0.3	<0.3
Kjeldahl Nitrogen (Total)	0.6	0.5	0.7
Total Phosphorus	<0.1	<0.1	<0.1
Hardness	70	70	10
Chloride	54	63.5	47.8
pH	7.65	7.93	7.64

NT = not tested

Table A-4. Analytical Results – Wheel Creek Grab Sampling			
Constituent	**Station WC002**	**Station WC003**	**Station WC004**
October 26, 2018 (Rising)			
TPH (mg/L)	<5	<5	<5
E. coli (MPN/100 ml)	186	166	172
Temp (C)	7.4	7.5	8.8
DO (mg/L)	11.28	11.36	9.6
pH	7.27	7.25	7.19
Sp. Cond. (mS/cm)	0.578	0.603	1.047

Table A-5. Rainfall and flow statistics			
Constituent	**Station WC002**	**Station WC003**	**Station WC004**
Rainfall (in.)	1.3	1.3	1.3
Duration (hrs.)	30	30	34
Intensity (in./hr.)	0.043	0.043	0.038
Discharge (cf.)	523,975	212,610	112,317

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WHEEL CREEK STORM MONITORING SUMMARY REPORT

NOVEMBER 15-16, 2018

INTRODUCTION

Versar field staff traveled to the site on November 15 to deploy siphon samplers and program the Sigma automated samplers to sample the event. Rainfall initiated at approximately 5:30 p.m. the evening of Thursday, November 15. At the Wheel Creek Rain Gauge Station, 1.16 inches of rain was recorded for the duration of the storm.

On the afternoon of November 16, field staff collected grab water samples to be tested for TPH and *E. coli* at all three stations that coincided with the falling limb of the storm. The *E. coli* samples were submitted to Enviro-Chem Laboratories for analysis shortly after collection.

Field staff traveled to the sites on November 16 to composite automated and suspended sediment concentration samples (SSC). Siphon samples were submitted to the laboratory for analysis of SSC on November 16. Composite samples were transported to the Harford County Government Department of Public Works Water and Sewer Laboratories on November 16.

The following issue occurred during the November 15-16 storm event:

Snow melt caused the stream levels to be elevated for an extended period, so the field team grabbed samples directly from the stream to represent the falling limbs for Station WC002 and Station WC004.

RESULTS

Hydrographs for the November 15-16 storm are presented in Figures A-1 and A-2 below. Laboratory analytical and field water quality results for the storm are shown in Tables A-1 through A-4. Rainfall and flow statistics for the November 15-16 event are shown in Table A-5.

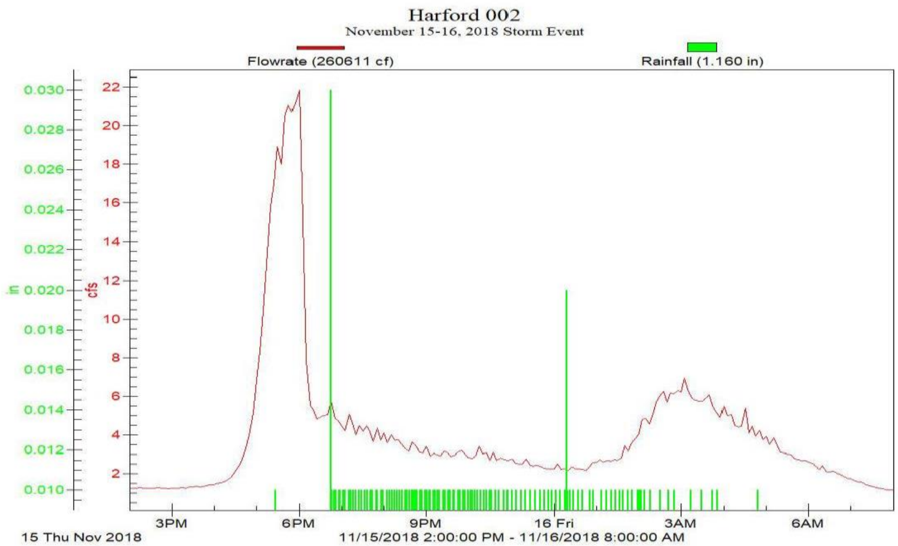

Figure A-1. Hydrograph at Station WC002 for November 15-16, 2018 storm. Rainfall data source: Wheel Creek Rain Gauge Station

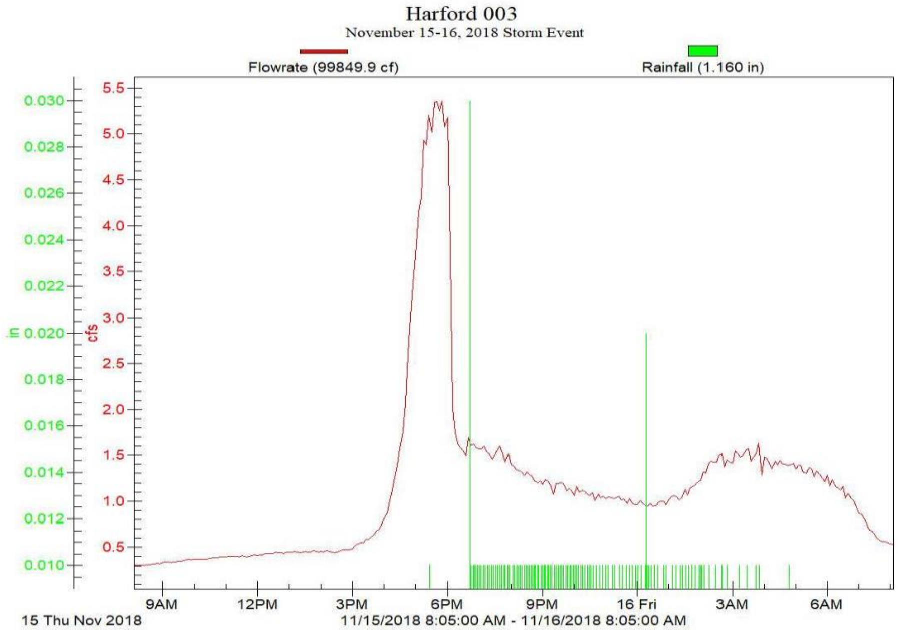

Figure A-2. Hydrograph at Station WC003 for November 15-16, 2018 storm. Rainfall data source: Wheel Creek Rain Gauge Station

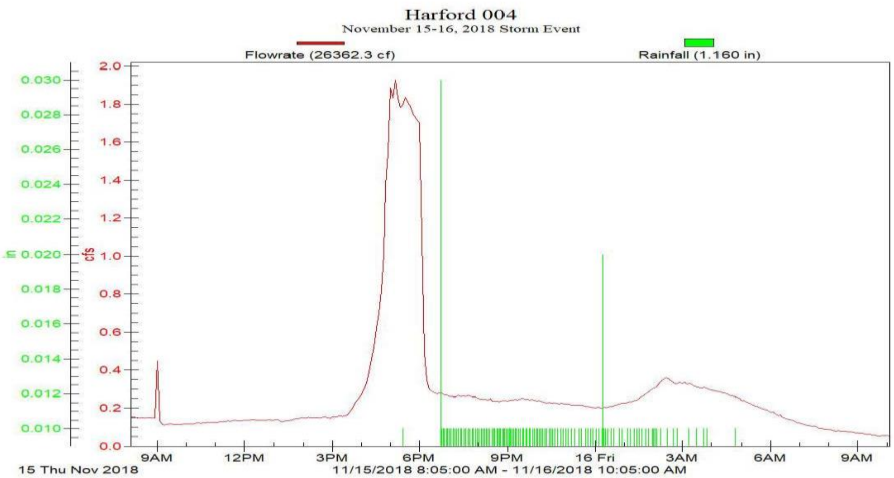

Figure A-3. Hydrograph at Station WC004 for November 15-16, 2018 storm. Rainfall data source: Wheel Creek Rain Gauge Station

Table A-1. Analytical results – Wheel Creek automated sampling, Rising Limb

Constituent	15-16-Nov-2018		
	Station WC002	Station WC003	Station WC004
	(mg/L)	(mg/L)	(mg/L)
5-Day BOD	1	1	1
Nitrate Nitrogen	NT	NT	NT
Nitrate-Nitrite Nitrogen	1.1	0.8	0.7
Orthophosphate Phosphorus	<0.1	<0.1	<0.1
Solids (Suspended)	8	15	7
Copper	0.004	0.003	0.005
Lead	<0.001	<0.001	<0.001
Zinc	0.042	0.043	0.05
Ammonia Nitrogen	0.3	<0.3	<0.3
Kjeldahl Nitrogen (Total)	0.6	0.6	0.8
Total Phosphorus	<0.1	<0.1	<0.1
Hardness	148	62	176
Chloride	671	1080	829
pH	6.87	6.78	6.76

NT = not tested

Table A-2. Analytical results – Wheel Creek automated sampling, Peak Limb			
Constituent	15-16-Nov-2018		
	Station WC002 (mg/L)	Station WC003 (mg/L)	Station WC004 (mg/L)
5-Day BOD	3	2	1
Nitrate Nitrogen	NT	NT	NT
Nitrate-Nitrite Nitrogen	0.4	0.4	0.2
Orthophosphate Phosphorus	<0.1	<0.1	<0.1
Solids (Suspended)	13	8	4
Copper	0.006	0.003	0.005
Lead	<0.001	<0.001	<0.001
Zinc	0.056	0.044	0.038
Ammonia Nitrogen	<0.3	<0.3	<0.3
Kjeldahl Nitrogen (Total)	0.8	0.7	<0.5
Total Phosphorus	<0.1	<0.1	<0.1
Hardness	110	134	40
Chloride	791	942	162
pH	6.82	6.83	7.24
NT = not tested			

Table A-3. Analytical results – Wheel Creek automated sampling, Falling Limb			
Constituent	15-16-Nov-2018		
	Station WC002 (mg/L)	Station WC003 (mg/L)	Station WC004 (mg/L)
5-Day BOD	1	1	1
Nitrate Nitrogen	NT	NT	NT
Nitrate-Nitrite Nitrogen	0.7	0.4	0.3
Orthophosphate Phosphorus	<0.1	<0.1	<0.1
Solids (Suspended)	5	4	2
Copper	<0.002	0.003	0.004
Lead	<0.001	<0.001	0.001
Zinc	0.033	0.036	0.044
Ammonia Nitrogen	<0.3	<0.3	<0.3
Kjeldahl Nitrogen (Total)	<0.5	0.5	<0.5
Total Phosphorus	<0.1	<0.1	<0.1
Hardness	70	148	36
Chloride	122	159	91
pH	7.2	7.26	7.47
NT = not tested			

Table A-4. Analytical Results – Wheel Creek Grab Sampling			
Constituent	**Station WC002**	**Station WC003**	**Station WC004**
November 16, 2018 (Falling)			
TPH (mg/L)	<5	<5	<5
E. coli (MPN/100 ml)	2420	1120	866
Temp (C)	2.7	2.2	1.2
DO (mg/L)	13.52	13.49	13.69
pH	7.2	7.1	7.47
Sp. Cond. (mS/cm)	0.484	0.546	0.385

Table A-5. Rainfall and flow statistics			
Constituent	**Station WC002**	**Station WC003**	**Station WC004**
Rainfall (in.)	1.16	1.16	1.16
Duration (hrs.)	18	18	18
Intensity (in./hr.)	0.064	0.064	0.064
Discharge (cf.)	260,611	91,338	22,932

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WHEEL CREEK STORM MONITORING SUMMARY REPORT

JANUARY 4-5, 2019

INTRODUCTION

Versar field staff traveled to the site on January 4 to deploy siphon samplers and program the Sigma automated samplers to sample the event. Rainfall initiated at approximately 10:00 p.m. the evening of Friday, January 4. At the Wheel Creek Rain Gauge Station, 0.32 inches of rain was recorded for the duration of the storm.

On the morning of January 7, field staff collected grab water samples to be tested for TPH and *E. coli* at all three stations that coincided with the falling limb of the storm. The *E. coli* samples were submitted to Enviro-Chem Laboratories for analysis shortly after collection.

Field staff traveled to the sites on January 7 to composite automated and suspended sediment concentration samples (SSC). SSC siphon samples were submitted to the laboratory for analysis on January 7. Composite samples were transported to the Harford County Government Department of Public Works Water and Sewer Laboratories on January 7.

The following issue occurred during the storm event:

At Station WC003, the ISCO flowmeter bubbler became detached from the sensor during the peak and falling limbs. The hydrograph from Station WC002 was used by field staff to composite the storm.

RESULTS

Hydrographs for the January 4-5 storm are presented in Figures A-1 through A-3 below. Laboratory analytical and field water quality results for the storm are shown in Tables A-1 through A-4. Rainfall and flow statistics for the January 4-5 event are shown in Table A-5.

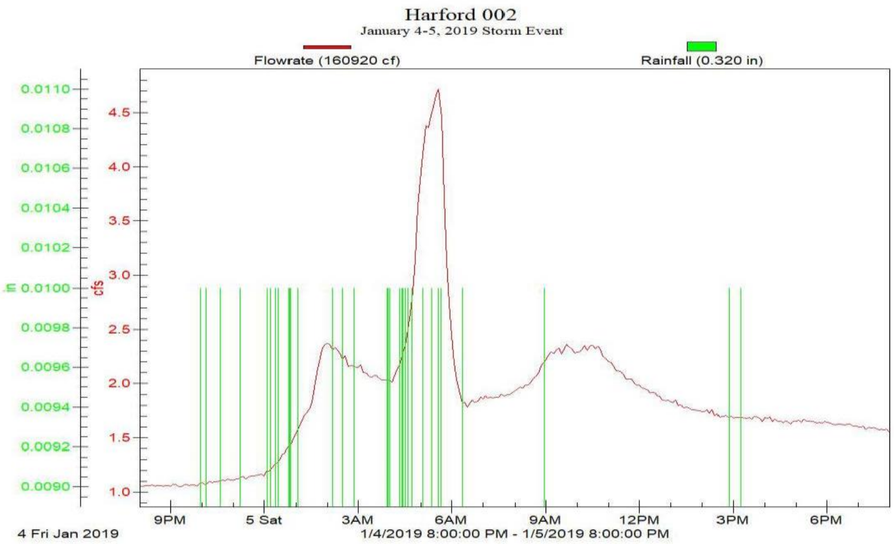

Figure A-1. Hydrograph at Station WC002 for January 4-5, 2019 storm. Rainfall data source: Wheel Creek Rain Gauge Station

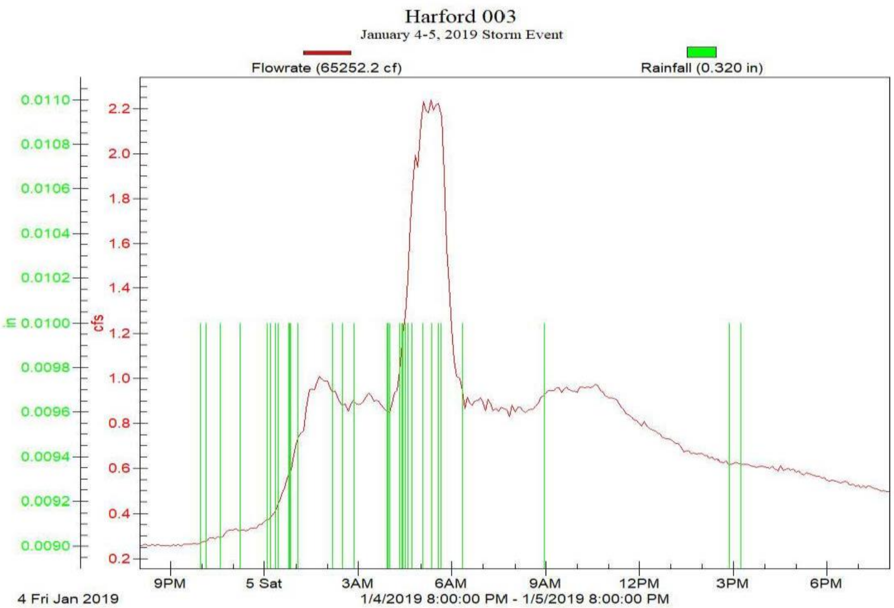

Figure A-2. Hydrograph at Station WC003 for January 4-5, 2019 storm. Rainfall data source: Wheel Creek Rain Gauge Station

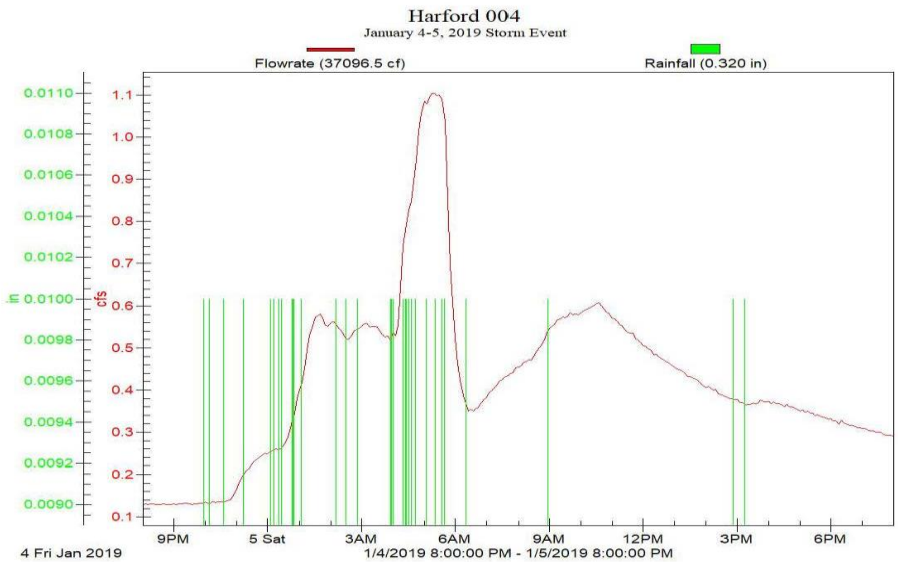

Figure A-3. Hydrograph at Station WC004 for January 4-5, 2019 storm. Rainfall data source: Wheel Creek Rain Gauge Station

Table A-1. Analytical results – Wheel Creek automated sampling, Rising Limb

Constituent	4-5-Jan-2019		
	Station WC002 (mg/L)	Station WC003 (mg/L)	Station WC004 (mg/L)
5-Day BOD	1	1	1
Nitrate Nitrogen	NT	NT	NT
Nitrate-Nitrite Nitrogen	1.7	1.3	0.9
Orthophosphate Phosphorus	<0.1	<0.1	<0.1
Solids (Suspended)	1	3	5
Copper	<0.002	0.002	0.006
Lead	<0.001	<0.001	<0.001
Zinc	0.017	0.017	0.025
Ammonia Nitrogen	0.3	<0.3	<0.3
Kjeldahl Nitrogen (Total)	<0.5	<0.5	0.6
Total Phosphorus	<0.1	<0.1	<0.1
Hardness	134	153	93
Chloride	107	130	84.9
pH	7.7	7.55	7.48

NT = not tested

Table A-2. Analytical results – Wheel Creek automated sampling, Peak Limb

Constituent	4-5-Jan-2019		
	Station WC002 (mg/L)	Station WC003 (mg/L)	Station WC004 (mg/L)
5-Day BOD	1	1	1
Nitrate Nitrogen	NT	NT	NT
Nitrate-Nitrite Nitrogen	0.8	0.7	0.5
Orthophosphate Phosphorus	<0.1	<0.1	<0.1
Solids (Suspended)	12	14	8
Copper	0.018	0.004	0.006
Lead	<0.001	<0.001	<0.001
Zinc	0.022	0.023	0.031
Ammonia Nitrogen	<0.3	<0.3	<0.3
Kjeldahl Nitrogen (Total)	0.6	0.5	0.6
Total Phosphorus	<0.1	<0.1	<0.1
Hardness	67	78	49
Chloride	61.6	69.6	47.9
pH	7.91	7.74	7.66

NT = not tested

Table A-3. Analytical results – Wheel Creek automated sampling, Falling Limb

Constituent	4-5-Jan-2019		
	Station WC002 (mg/L)	Station WC003 (mg/L)	Station WC004 (mg/L)
5-Day BOD	1	1	1
Nitrate Nitrogen	NT	NT	NT
Nitrate-Nitrite Nitrogen	1.1	0.9	0.8
Orthophosphate Phosphorus	<0.1	<0.1	<0.1
Solids (Suspended)	1	2	1
Copper	0.002	0.003	0.004
Lead	<0.001	<0.001	<0.001
Zinc	0.014	0.016	0.021
Ammonia Nitrogen	<0.3	<0.3	<0.3
Kjeldahl Nitrogen (Total)	<0.5	<0.5	<0.5
Total Phosphorus	<0.1	<0.1	<0.1
Hardness	96	112	86
Chloride	77.3	105	78.3
pH	7.75	7.59	7.49

NT = not tested

Table A-4. Analytical Results – Wheel Creek Grab Sampling			
Constituent	**Station WC002**	**Station WC003**	**Station WC004**
January 7, 2019 (Falling)			
TPH (mg/L)	<5	<5	<5
E. coli (MPN/100 ml)	4.1	8.5	13.2
Temp (C)	5.7	5.6	7.3
DO (mg/L)	13.29	12.61	11.32
pH	7.66	8.24	7.3
Sp. Cond. (mS/cm)	0.511	0.575	0.726

Table A-5. Rainfall and flow statistics			
Constituent	**Station WC002**	**Station WC003**	**Station WC004**
Rainfall (in.)	0.32	0.32	0.32
Duration (hrs.)	24	24	24
Intensity (in./hr.)	0.013	0.013	0.013
Discharge (cf.)	269,754	95,118	37,096

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WHEEL CREEK STORM MONITORING SUMMARY REPORT

FEBRUARY 20-21, 2019

INTRODUCTION

Versar field staff traveled to the site on February 19 to deploy siphon samplers and program the Sigma automated samplers to sample the event. Rainfall initiated at approximately 3:40 p.m. the afternoon of Wednesday, February 20. At a local Rain Gauge Station, 0.15 inches of rain was recorded for the duration of the storm.

On the morning of February 21, field staff collected grab water samples to be tested for TPH and *E. coli* at all three stations that coincided with the falling limb of the storm. The *E. coli* samples were submitted to Enviro-Chem Laboratories for analysis shortly after collection.

Field staff traveled to the sites on February 21 to composite automated and suspended sediment concentration samples (SSC). Siphon samples were submitted to the laboratory for analysis of SSC on February 21. Composite samples, including TPH, were transported to the Harford County Government Department of Public Works Water and Sewer Laboratories on February 21.

The following issue occurred during the storm event:

The sampler battery at Station WC003 died after the peak of the storm, so staff used the hydrograph from Station WC002 for the storm composite. A manual grab sample was taken directly from the stream during the composite to represent the falling limb sample. The onsite rain gauge failed to record rainfall; therefore, the field staff used rainfall data from a local Weather Underground rain gauge (KMDBELAI56).

RESULTS

Hydrographs for the February 20-21 storm are presented in Figures A-1 through A-3 below. Laboratory analytical and field water quality results for the storm are shown in Tables A-1 through A-4. Rainfall and flow statistics for the February 20-21 event are shown in Table A-5.

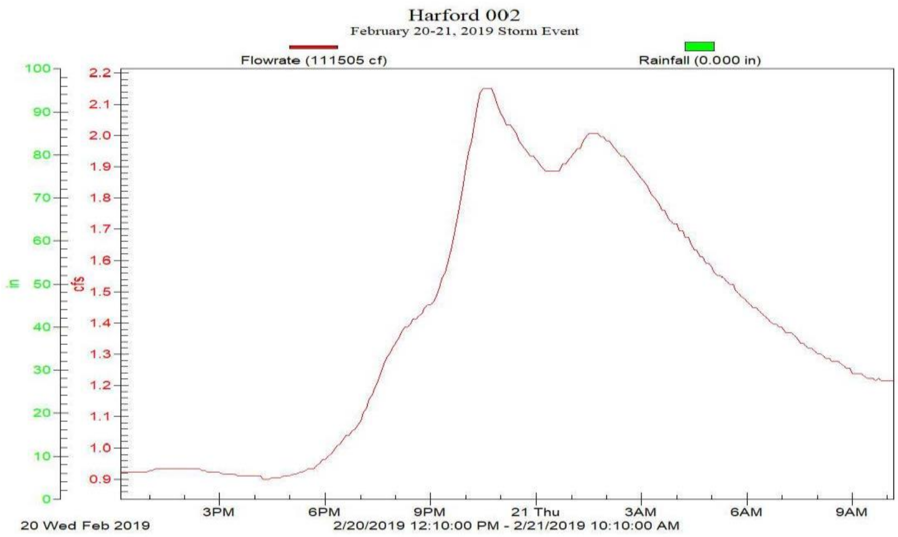

Figure A-1. Hydrograph at Station WC002 for February 20-21, 2019 storm.

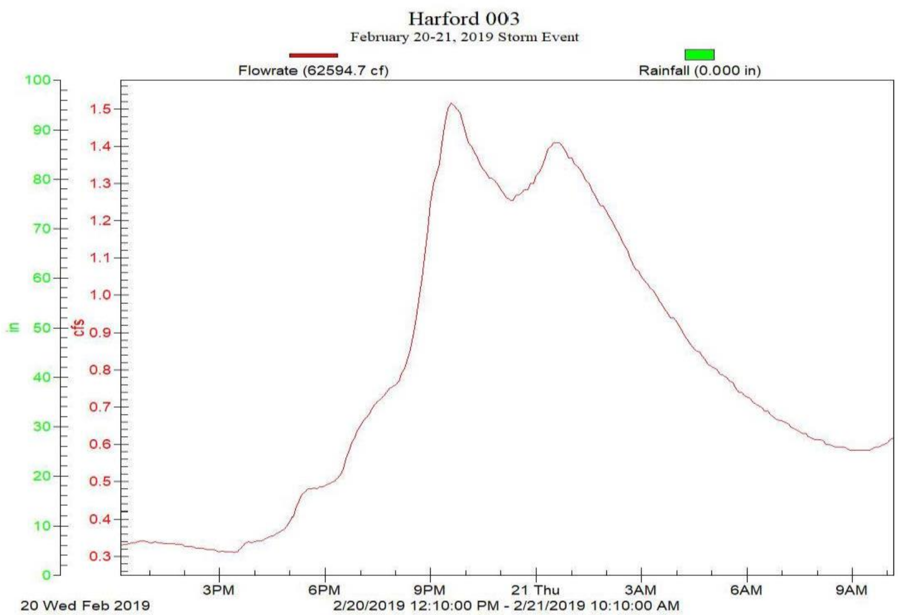

Figure A-2. Hydrograph at Station WC003 for February 20-21, 2019 storm.

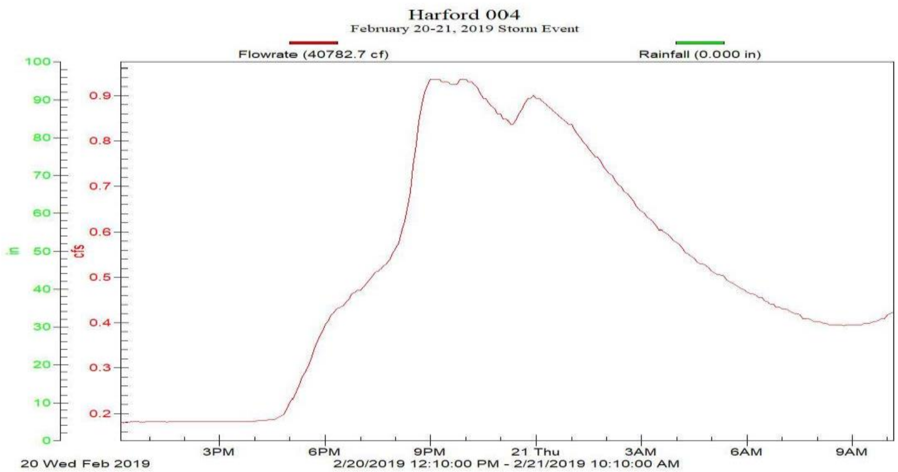

Figure A-3. Hydrograph at Station WC004 for February 20-21, 2019 storm.

Table A-1. Analytical results – Wheel Creek automated sampling, Rising Limb

Constituent	20-21-Feb-2019		
	Station WC002 (mg/L)	Station WC003 (mg/L)	Station WC004 (mg/L)
5-Day BOD	<1	<1	<1
Nitrate Nitrogen	NT	NT	NT
Nitrate-Nitrite Nitrogen	1.7	1.1	0.9
Orthophosphate Phosphorus	<0.1	<0.1	<0.1
Solids (Suspended)	4	6	9
Copper	<0.002	0.003	0.004
Lead	<0.001	<0.001	<0.001
Zinc	0.025	0.024	0.039
Ammonia Nitrogen	<0.3	<0.3	<0.3
Kjeldahl Nitrogen (Total)	<0.5	0.5	0.7
Total Phosphorus	<0.1	<0.1	<0.1
Hardness	180	192	136
Chloride	1080	1750	880
pH	7.72	7.32	7.4

NT = not tested

Table A-2. Analytical results – Wheel Creek automated sampling, Peak Limb			
Constituent	20-21-Feb-2019		
	Station WC002 (mg/L)	Station WC003 (mg/L)	Station WC004 (mg/L)
5-Day BOD	<1	<1	1
Nitrate Nitrogen	NT	NT	NT
Nitrate-Nitrite Nitrogen	1	0.8	0.6
Orthophosphate Phosphorus	<0.1	<0.1	<0.1
Solids (Suspended)	8	6	11
Copper	0.003	0.004	0.005
Lead	<0.005	<0.001	<0.001
Zinc	0.038	0.037	0.045
Ammonia Nitrogen	<0.3	<0.3	<0.3
Kjeldahl Nitrogen (Total)	0.6	0.5	0.9
Total Phosphorus	<0.1	<0.1	<0.1
Hardness	178	158	136
Chloride	1750	900	1200
pH	7.55	7.58	7.28
NT = not tested			

Table A-3. Analytical results – Wheel Creek automated sampling, Falling Limb			
Constituent	20-21-Feb-2019		
	Station WC002 (mg/L)	Station WC003 (mg/L)	Station WC004 (mg/L)
5-Day BOD	<1	<1	1
Nitrate Nitrogen	NT	NT	NT
Nitrate-Nitrite Nitrogen	1	0.8	0.8
Orthophosphate Phosphorus	<0.1	<0.1	<0.1
Solids (Suspended)	3	4	10
Copper	<0.002	<0.002	0.004
Lead	<0.001	<0.001	<0.001
Zinc	0.031	0.023	0.052
Ammonia Nitrogen	<0.3	<0.3	<0.3
Kjeldahl Nitrogen (Total)	<0.5	0.5	0.8
Total Phosphorus	<0.1	<0.1	<0.1
Hardness	158	140	108
Chloride	970	527	692
pH	7.78	7.73	7.5
NT = not tested			

Table A-4. Analytical Results – Wheel Creek Grab Sampling			
Constituent	**Station WC002**	**Station WC003**	**Station WC004**
February 21, 2019 (Falling)			
TPH (mg/L)	<5	<5	<5
E. coli (MPN/100 ml)	37.9	25.3	387
Temp (C)	2.2	2.5	2.1
DO (mg/L)	14.03	13.85	13.61
pH	7.94	7.73	7.49
Sp. Cond. (mS/cm)	2.48	1.875	3.014

Table A-5. Rainfall and flow statistics			
Constituent	**Station WC002**	**Station WC003**	**Station WC004**
Rainfall (in.)	0.15	0.15	0.15
Duration (hrs.)	22	22	22
Intensity (in./hr.)	0.007	0.007	0.007
Discharge (cf.)	111,505	62,594	40,782

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WHEEL CREEK STORM MONITORING SUMMARY REPORT

JUNE 10-11, 2019

INTRODUCTION

Versar field staff traveled to the site on June 9 to deploy siphon samplers and program the Sigma automated samplers to sample the event. Rainfall initiated at approximately 1:45 a.m. the morning of Monday, June 10. At the Wheel Creek Rain Gauge Station, 0.48 inches of rain was recorded for the duration of the storm.

On the morning of June 11, field staff collected grab water samples to be tested for TPH and *E. coli* at all three stations that coincided with the falling limb of the storm. The *E. coli* samples were submitted to Enviro-Chem Laboratories for analysis shortly after collection.

Field staff traveled to the sites on June 11 to composite automated and suspended sediment concentration samples (SSC). SSC siphon samples were submitted to the laboratory for analysis on June 11. Composite samples, including TPH, were transported to the Harford County Government Department of Public Works Water and Sewer Laboratories on June 11.

The following issue occurred during the storm event:

The ISCO bubbler flowmeter failed at Station WC003 due to debris pinching the tubing. Versar staff used the hydrograph from Station WC002 to determine discrete sample volumes to use for the composite samples at this station.

RESULTS

Hydrographs for the June 10-11 storm are presented in Figures A-1 through A-3 below. Laboratory analytical and field water quality results for the storm are shown in Tables A-1 through A-4. Rainfall and flow statistics for the June 10-11 event are shown in Table A-5.

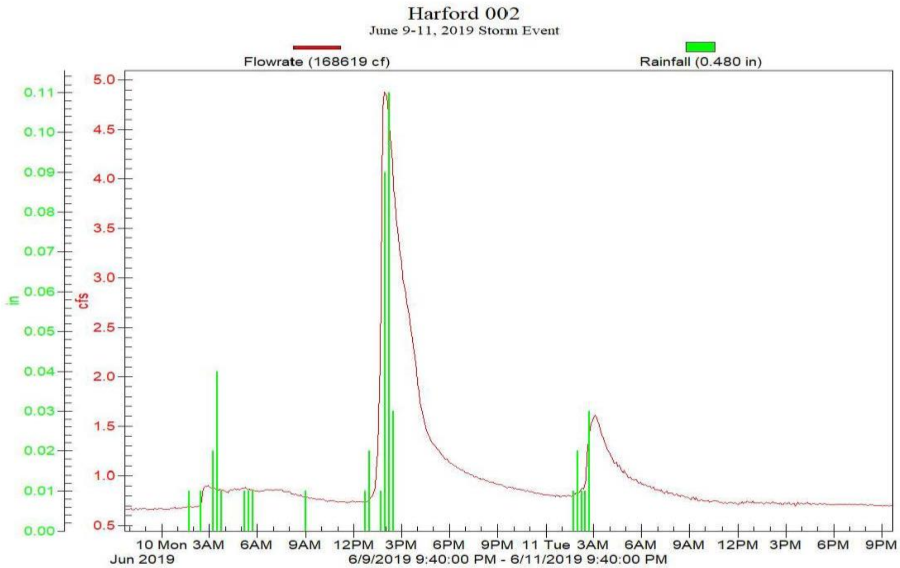

Figure A-1. Hydrograph at Station WC002 for June 10-11, 2019 storm. Rainfall data source: Wheel Creek Rain Gauge Station

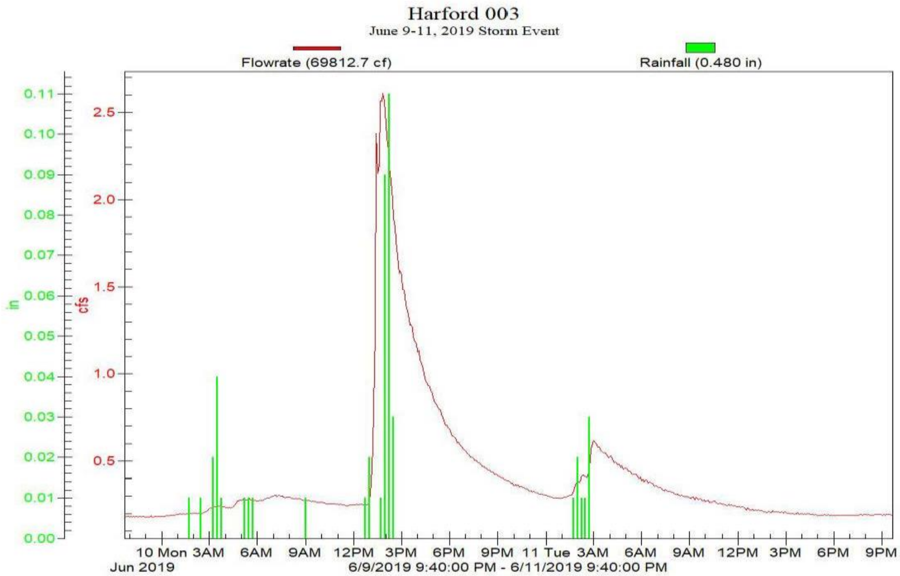

Figure A-2. Hydrograph at Station WC003 for June 10-11, 2019 storm. Rainfall data source: Wheel Creek Rain Gauge Station

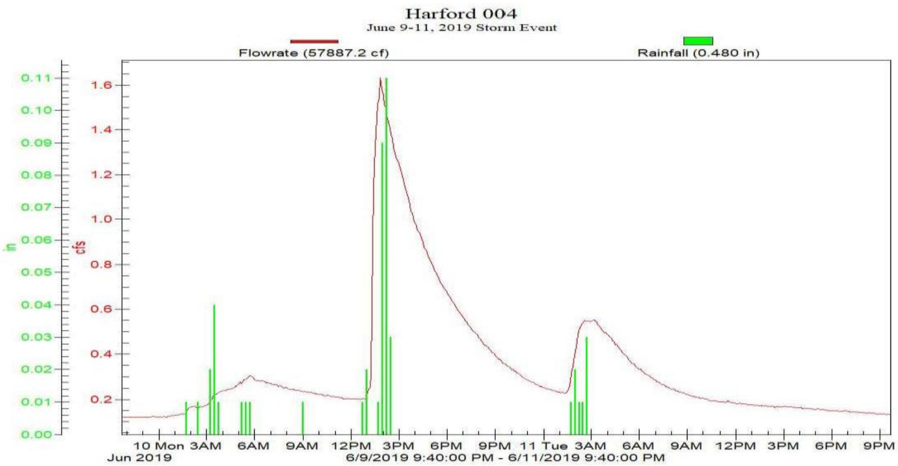

Figure A-3. Hydrograph at Station WC004 for June 10-11, 2019 storm. Rainfall data source: Wheel Creek Rain Gauge Station

Table A-1. Analytical results – Wheel Creek automated sampling, Rising Limb

Constituent	10-11-June-2019		
	Station WC002 (mg/L)	Station WC003 (mg/L)	Station WC004 (mg/L)
5-Day BOD	<1	<1	1
Nitrate Nitrogen	NT	NT	NT
Nitrate-Nitrite Nitrogen	1.4	0.9	1.8
Orthophosphate Phosphorus	0.02	0.04	0.04
Solids (Suspended)	<1	5	12
Copper	<0.002	<0.002	0.003
Lead	<0.001	<0.001	<0.001
Zinc	0.012	0.024	0.042
Ammonia Nitrogen	0.16	0.09	0.06
Kjeldahl Nitrogen (Total)	<0.5	0.5	0.9
Total Phosphorus	0.02	0.02	0.04
Hardness	152	182	183
Chloride	122	147	142
pH	7.19	7.25	6.79

NT = not tested

Table A-2. Analytical results – Wheel Creek automated sampling, Peak Limb			
Constituent	**10-11-June-2019**		
	Station WC002 (mg/L)	**Station WC003 (mg/L)**	**Station WC004 (mg/L)**
5-Day BOD	2	4	3
Nitrate Nitrogen	NT	NT	NT
Nitrate-Nitrite Nitrogen	0.6	0.4	0.4
Orthophosphate Phosphorus	0.07	0.08	0.06
Solids (Suspended)	13	58	12
Copper	<0.002	<0.004	<0.004
Lead	<0.001	<0.002	<0.002
Zinc	0.023	0.077	0.051
Ammonia Nitrogen	0.09	0.1	0.16
Kjeldahl Nitrogen (Total)	0.7	1.1	1.3
Total Phosphorus	0.05	0.12	0.07
Hardness	95	92	79
Chloride	51.4	66.5	38.7
pH	7.35	7.4	7.12
NT = not tested			

Table A-3. Analytical results – Wheel Creek automated sampling, Falling Limb			
Constituent	**10-11-June-2019**		
	Station WC002 (mg/L)	**Station WC003 (mg/L)**	**Station WC004 (mg/L)**
5-Day BOD	<1	1	2
Nitrate Nitrogen	NT	NT	NT
Nitrate-Nitrite Nitrogen	1	0.5	0.8
Orthophosphate Phosphorus	0.04	0.07	0.04
Solids (Suspended)	2	3	5
Copper	<0.002	<0.002	<0.002
Lead	<0.001	<0.001	<0.001
Zinc	0.012	0.023	0.028
Ammonia Nitrogen	0.06	0.07	0.09
Kjeldahl Nitrogen (Total)	0.6	0.6	1
Total Phosphorus	0.02	0.02	0.04
Hardness	122	110	82
Chloride	78.9	87.3	69.9
pH	7.2	7.32	6.98
NT = not tested			

Table A-4. Analytical Results – Wheel Creek Grab Sampling			
Constituent	**Station WC002**	**Station WC003**	**Station WC004**
June 11, 2019 (Falling)			
TPH (mg/L)	<5	<5	<5
E. coli (MPN/100 ml)	687	291	435
Temp (C)	15.1	16.6	16.6
DO (mg/L)	8.86	8.97	6.4
pH	7.05	7	6.84
Sp. Cond. (mS/cm)	0.391	0.299	0.381

Table A-5. Rainfall and flow statistics			
Constituent	**Station WC002**	**Station WC003**	**Station WC004**
Rainfall (in.)	0.48	0.48	0.48
Duration (hrs.)	48	48	48
Intensity (in./hr.)	0.010	0.010	0.010
Discharge (cf.)	168,619	69,812	57,887

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WHEEL CREEK STORM MONITORING SUMMARY REPORT

JUNE 12-13, 2019

INTRODUCTION

Versar field staff traveled to the site on June 12 to deploy siphon samplers and program the Sigma automated samplers to sample the event. Rainfall initiated at approximately 10:45 p.m. the evening of Wednesday, June 12. At the Wheel Creek Rain Gauge Station, 0.53 inches of rain was recorded for the duration of the storm.

On the morning of June 13, field staff collected grab water samples to be tested for TPH and *E. coli* at all three stations that coincided with the falling limb of the storm. The *E. coli* samples were submitted to Enviro-Chem Laboratories for analysis shortly after collection.

Field staff traveled to the sites on June 13 to composite automated and suspended sediment concentration samples (SSC). Siphon samples were submitted to the laboratory for analysis of SSC on June 13. Composite samples, including TPH, were transported to the Harford County Government Department of Public Works Water and Sewer Laboratories on June 13.

The following issue occurred during the storm event:

The battery failed on the automated sampler at Station WC002, resulting in no samples collected.

RESULTS

Hydrographs for the June 12-13 storm are presented in Figures A-1 through A-2 below. Laboratory analytical and field water quality results for the storm are shown in Tables A-1 through A-4. Rainfall and flow statistics for the June 12-13 event are shown in Table A-5.

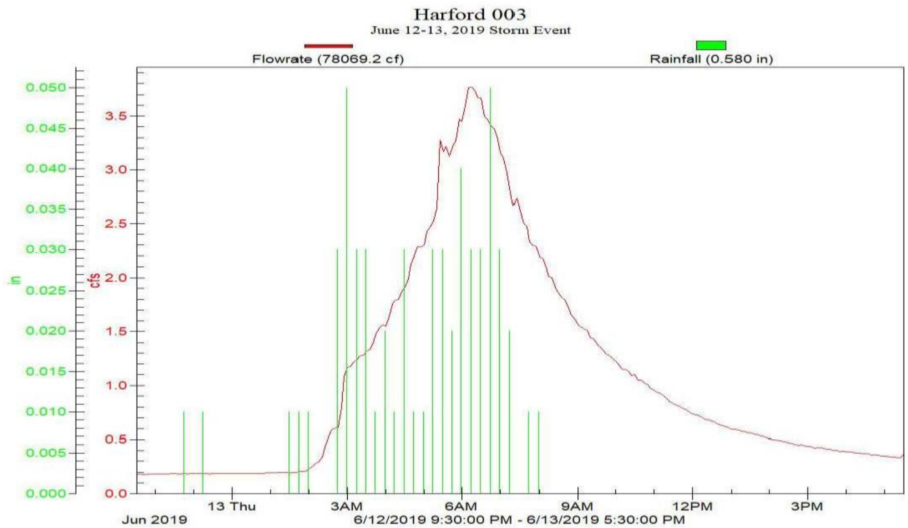

Figure A-1. Hydrograph at Station WC003 for June 12-13, 2019 storm. Rainfall data source: Akisson Rain Gauge Station

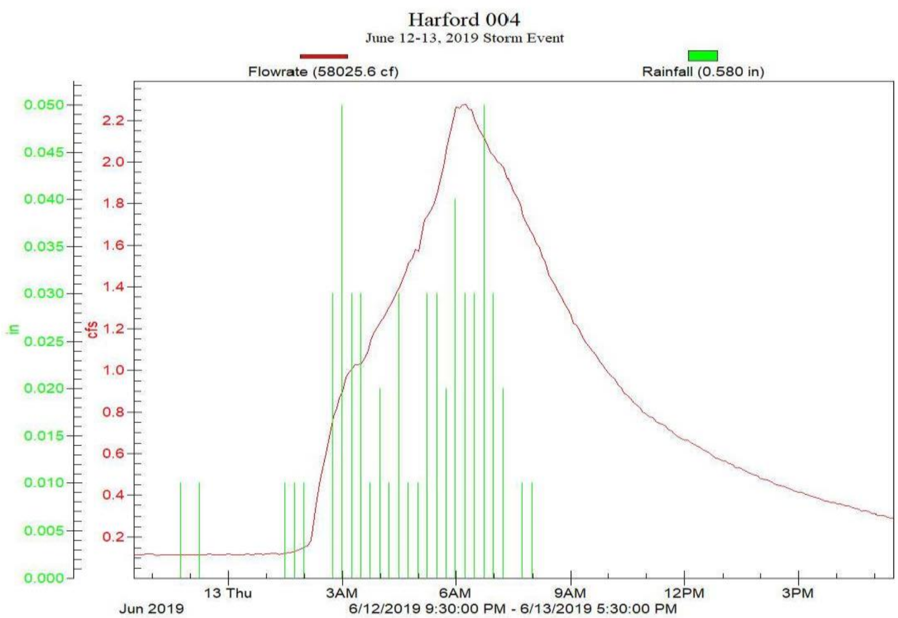

Figure A-2. Hydrograph at Station WC004 for June 12-13, 2019 storm. Rainfall data source: Akisson Rain Gauge Station

Table A-1. Analytical results – Wheel Creek automated sampling, Rising Limb			
Constituent	12-13-June-2019		
	Station WC002 (mg/L)	Station WC003 (mg/L)	Station WC004 (mg/L)
5-Day BOD	N/A	2	3
Nitrate Nitrogen	N/A	NT	NT
Nitrate-Nitrite Nitrogen	N/A	0.7	0.3
Orthophosphate Phosphorus	N/A	<0.1	0.06
Solids (Suspended)	N/A	37	23
Copper	N/A	<0.004	0.008
Lead	N/A	<0.002	0.002
Zinc	N/A	0.046	0.049
Ammonia Nitrogen	N/A	0.17	0.16
Kjeldahl Nitrogen (Total)	N/A	0.7	1.4
Total Phosphorus	N/A	0.08	0.12
Hardness	N/A	146	57
Chloride	N/A	120	44.9
pH	N/A	7.04	6.88
NT = not tested, N/A = not applicable			

Table A-2. Analytical results – Wheel Creek automated sampling, Peak Limb			
Constituent	12-13-June-2019		
	Station WC002 (mg/L)	Station WC003 (mg/L)	Station WC004 (mg/L)
5-Day BOD	N/A	3	2
Nitrate Nitrogen	N/A	NT	NT
Nitrate-Nitrite Nitrogen	N/A	0.2	<0.02
Orthophosphate Phosphorus	N/A	0.05	0.06
Solids (Suspended)	N/A	48	9
Copper	N/A	0.009	0.005
Lead	N/A	0.002	<0.001
Zinc	N/A	0.077	0.033
Ammonia Nitrogen	N/A	0.11	0.12
Kjeldahl Nitrogen (Total)	N/A	1.1	1
Total Phosphorus	N/A	0.13	0.09
Hardness	N/A	70	31
Chloride	N/A	48.2	26.3
pH	N/A	7.33	7.14
NT = not tested, N/A = not applicable			

Table A-3. Analytical results – Wheel Creek automated sampling, Falling Limb			
Constituent	**12-13-June-2019**		
	Station WC002 (mg/L)	**Station WC003 (mg/L)**	**Station WC004 (mg/L)**
5-Day BOD	N/A	2	2
Nitrate Nitrogen	N/A	NT	NT
Nitrate-Nitrite Nitrogen	N/A	0.2	0.2
Orthophosphate Phosphorus	N/A	0.07	0.06
Solids (Suspended)	N/A	10	6
Copper	N/A	<0.004	0.003
Lead	N/A	<0.002	<0.001
Zinc	N/A	0.024	0.032
Ammonia Nitrogen	N/A	0.08	0.13
Kjeldahl Nitrogen (Total)	N/A	0.8	0.9
Total Phosphorus	N/A	0.05	0.04
Hardness	N/A	65	34
Chloride	N/A	52.8	28.2
pH	N/A	7.28	7.05
NT = not tested, N/A = not applicable			

Table A-4. Analytical Results – Wheel Creek Grab Sampling			
Constituent	**Station WC002**	**Station WC003**	**Station WC004**
June 13, 2018 (Falling)			
TPH (mg/L)	<5	<5	<5
E. coli (MPN/100 ml)	>2420	517	166
Temp (C)	15.9	16.6	17.1
DO (mg/L)	9.19	8.97	8.01
pH	7.33	7	6.96
Sp. Cond. (mS/cm)	0.251	0.299	0.155

Table A-5. Rainfall and flow statistics

Constituent	Station WC002	Station WC003	Station WC004
Rainfall (in.)	N/A	0.58	0.58
Duration (hrs.)	N/A	20	20
Intensity (in./hr.)	N/A	0.029	0.029
Discharge (cf.)	N/A	78,069	58,025

N/A = not applicable

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APPENDIX B

RATING CURVES

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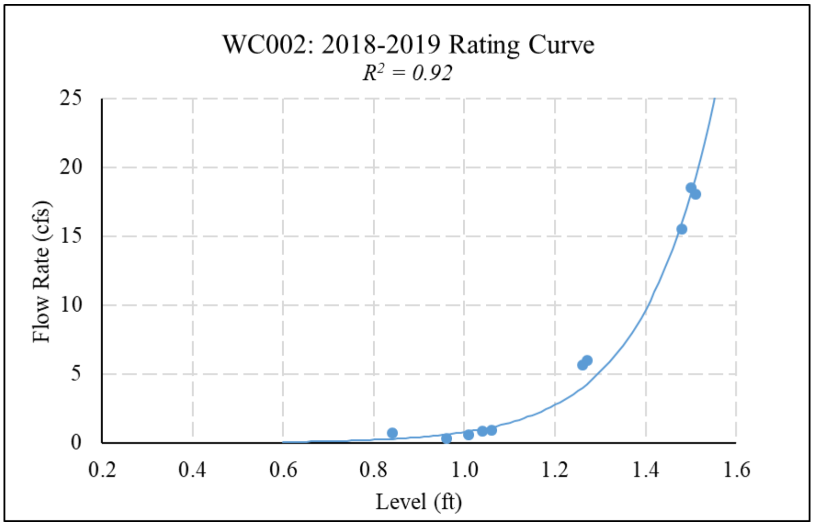
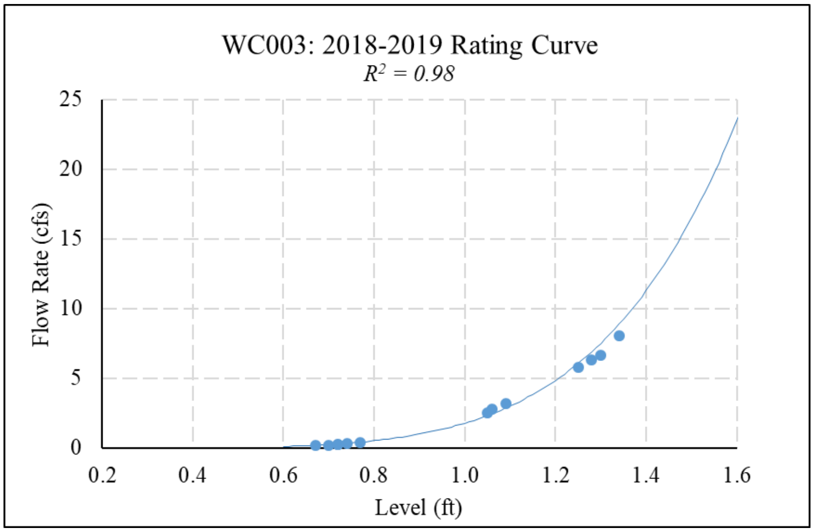
Table B-1. Station WC002 rating curve from data points collected in 2018-2019	
Level (ft)	**Flow Rate (cfs)**
0.84	0.726
0.96	0.290
1.01	0.577
1.04	0.840
1.06	0.924
1.26	5.674
1.27	5.970
1.48	15.545
1.50	18.547
1.51	18.062

Table B-2. Station WC003 rating curve from data points collected in 2018-2019	
Level (ft)	**Flow Rate (cfs)**
0.67	0.201
0.70	0.180
0.72	0.280
0.72	0.287
0.74	0.325
0.77	0.406
1.05	2.512
1.06	2.774
1.09	3.168
1.25	5.821
1.28	6.336
1.30	6.669
1.34	8.067

Table B-3. Station WC004 rating curve from data points collected in 2018-2019	
Level (ft)	**Flow Rate (cfs)**
0.43	0.010
0.52	0.137
0.53	0.208
0.55	0.243
0.88	2.043
0.89	2.063
0.92	2.308
0.95	2.770
0.96	2.895
0.99	3.362
1.00	3.623





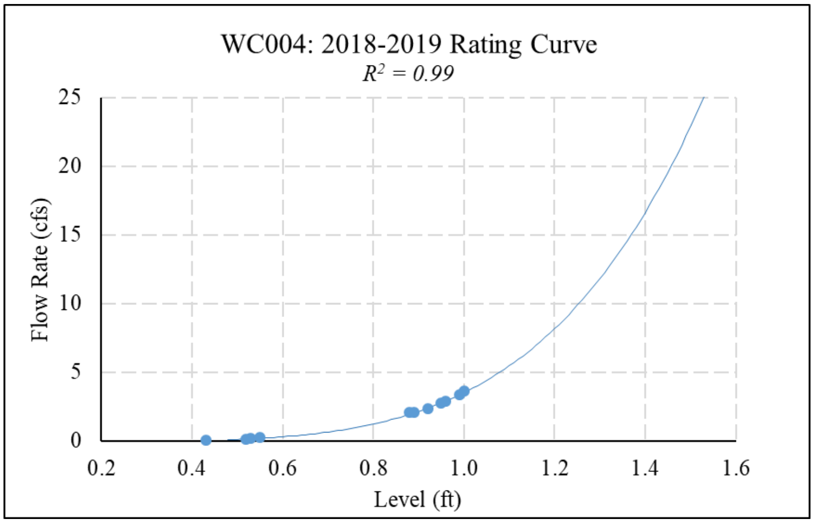


Figure B-1. Rating Curves for Stations WC002, WC003, and WC004

APPENDIX C

RAINFALL TOTALS

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Table C-1. July 2018-June 2019 rainfall data from USGS Atkisson (inches)

Day	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June
1	0	0	0.02	0	0	0.31	0.02	0	0.59	0	0	0
2	0	0.19	0.01	0	1.31	0.4	0	0.04	0.16	0.01	0.08	0
3	0	0.18	0	0	0.03	0.01	0	0.01	0.47	0	0.16	0
4	0	0.07	0	---	0	0	0.05	0	0.39	0	0.04	0
5	0	0	0	---	0.97	0	0.29	0	0	0.11	1.22	0.23
6	0.04	0	0.26	---	0.88	0	0	0.31	0	0	0	0.1
7	0	0	0.25	---	0.01	0	0	0.02	0	0	0	0
8	0	0.63	0.58	---	0	0	0.29	0.02	0.01	0.01	0	0
9	0	0.01	3.13	---	0.75	0	0	0	0.06	0	0	0
10	0	0	0.26	---	0	0	0	0	0.63	0	0.37	0.4
11	0	0.29	0.01	---	0	0	0	0	0	0	0.33	0.08
12	0	0.01	0.02	---	0.35	0	0	0.75	0	0.36	1.11	0.02
13	0	0.77	0.01	---	0.71	0	0	0.54	0	0.15	0.78	1.21
14	0	0.05	0.01	---	0	0.26	0	0	0	0.01	0.01	0
15	0.09	0	0	---	0.73	1.27	0.09	0	0.17	0.24	0	0
16	0	0	0	---	0.67	0.7	0.09	0	0	0	0.03	0.01
17	1.68	0	0.6	0.01	0	0	0	0.18	0	0	0	0.07
18	0	0.05	2.15	0	0	0	0.09	0.2	0	0	0	0.09
19	0	0.03	0	0	0	0	0.85	0	0	0.22	0	1.12
20	0	0.01	0	0.07	0	1.02	0.45	0	0	0.16	0	0.03
21	2.06	1.44	0	0.01	0	0.43	0	0.54	3.05	0	0	0
22	2.57	0.04	0	0	0	0.01	0	0	0.28	0	0	0
23	0.86	0	1.15	0	0	0	0	0.1	0	0	0.02	0
24	1.89	0	0.13	0	1.97	0.01	1.34	0.47	0	0	0.04	0
25	0.85	0	0.71	0	0	0	0	0	0.07	0	0.21	0.45
26	0	0	0.24	0.57	0.57	0	0	0	0	0.72	1.09	0
27	1.79	0	0.64	0.82	0	0	0	0	0	0.03	0	0
28	0	0	0.34	0.06	0	1.35	0	0	0	0.02	0.37	0
29	0	0	0	0	0	0	0.12		0	0	0.02	0.26
30	0	0	0	0	0.02	0	0.07		0	0	0.53	0
31	0	2.6		0		0.65	0		0.02		0	
Total Rain	**11.83**	**6.37**	**10.52**	**1.54**	**8.97**	**6.42**	**3.75**	**3.18**	**5.90**	**2.04**	**6.41**	**4.07**
											Annual Rainfall Total:	**71.00**

“---“ = gauge offline

Table C-2. July 2018-June 2019 rainfall data from Wheel Creek HOBO logger (inches)

Day	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June
1	0	0.74	0.04	0	0	0.27	0.02	0	0.53	0	0	0.01
2	0	0.18	0.01	0	1.22	0.39	0	0	0.15	0	0.08	0.01
3	0	0.12	0	0	0.03	0	0	0.13	0.42	0	0.14	0
4	0	0.08	0	0.02	0	0	0.04	0	0.36	0	0.03	0.01
5	0	0	0	0	0.87	0	0.28	0	0	0.10	1.10	0.01
6	0.04	0	0.16	0	0.91	0	0	0.28	0	0	0	0
7	0	0	0.24	0	0	0	0	0.02	0	0	0	0.01
8	0	0.61	0.56	0.32	0	0	0.26	0.02	0.02	0	0	0.01
9	0	0	3.05	0.01	0.69	0	0	0	0.04	0.01	0	0
10	0	0	0.28	0	0.01	0	0	0	0.56	0	0.34	0
11	0	0.18	0.02	0.91	0	0	0	0	0	0	0.29	0
12	0	0.01	0	0	0.31	0	0	1.08	0	0.40	1.04	0.01
13	0	0.64	0.01	0.10	0.63	0	0	0.31	0	0.15	0.81	0
14	0	0.05	0	0.02	0	0.23	0	0	0	0.01	0.02	0.01
15	0.07	0	0	0.18	0.83	1.18	0	0	0.12	0.18	0	0
16	0	0	0	0	0.33	0.64	0.13	0	0	0	0.02	0.01
17	1.78	0	0.49	0	0	0	0.01	0.15	0	0	0	0
18	0	0.04	2.03	0	0	0	0.09	0.19	0	0	0	0.01
19	0	0.04	0	0	0	0	0.74	0	0	0.20	0	0.01
20	0	0.01	0	0.07	0	0.94	0.40	0	0	0.14	0	0.01
21	1.82	1.50	0	0.01	0	0.41	0	0.47	2.63	0	0	0.01
22	2.08	0.03	0	0	0	0.01	0	0	0.26	0	0	0.01
23	0.70	0	1.04	0	0	0	0	0.07	0	0	0.01	0
24	1.79	0	0.13	0	1.87	0.01	1.19	0.45	0	0	0.01	0.01
25	0.82	0	0.63	0	0.01	0	0	0	0.08	0	0.12	0.01
26	0	0	0.19	0.55	0.54	0	0	0	0	0.74	0.64	0
27	1.56	0	0.54	0.75	0	0	0	0	0	0.01	0.09	0
28	0	0	0.33	0.05	0	1.28	0	0	0	0.02	0.20	0.01
29	0	0	0	0.01	0	0	0.09		0	0	0.02	0
30	0.04	0	0	0	0.02	0	0		0	0	0.07	0
31	0	2.51		0		0.61	0		0.01		0.05	
Total Rain	**10.70**	**6.74**	**9.75**	**3.00**	**8.27**	**5.97**	**3.25**	**3.17**	**5.18**	**1.96**	**5.08**	**0.17**
											Annual Rainfall Total:	**63.24**

"---" = gauge clogged

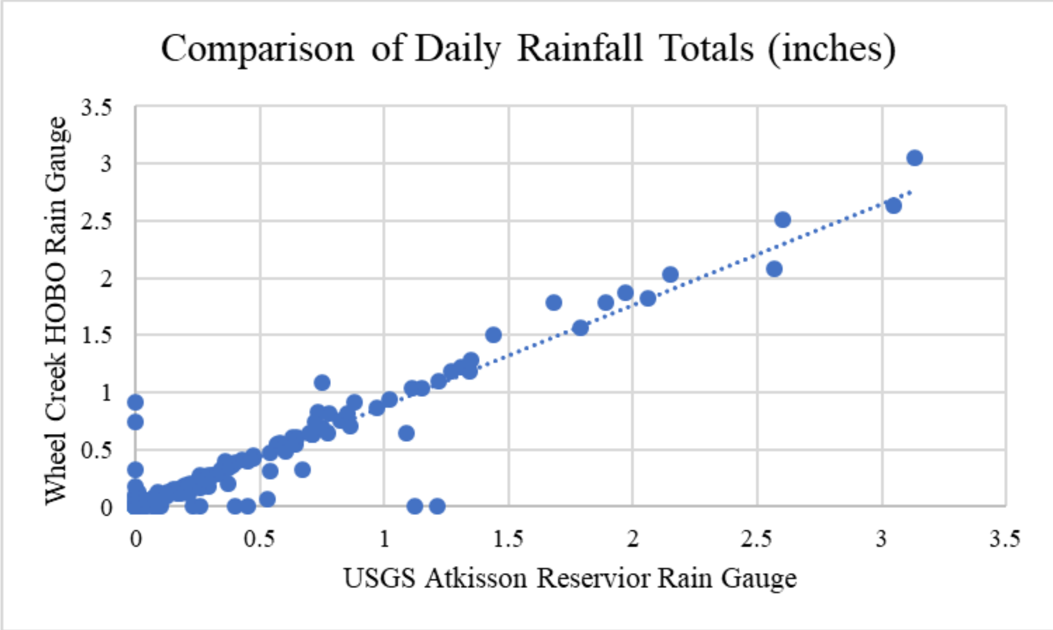

Figure C-1. Comparison of Daily Rainfall Totals for the USGS and Wheel Creek gauges

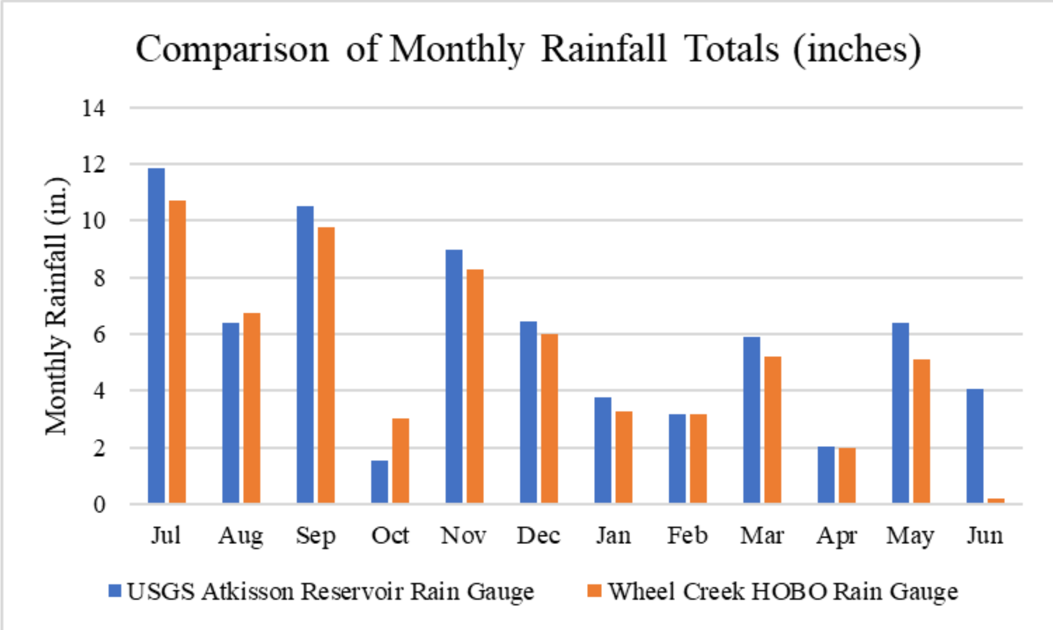

Figure C-2. Comparison of Monthly Rainfall Totals for the USGS and Wheel Creek gauges. In June, the Wheel Creek rain gauge became fouled and blocked, resulting in lost data for the majority of the month.

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APPENDIX D

TOTAL ANNUAL LOADS AND YIELDS OF POLLUTANTS AT WHEEL CREEK STUDY STATIONS

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Table D-1. Baseflow and storm flow MCs and EMCs, total annual loads, and annual yields (July 2018-June 2019)							
Analyte	**Station**	**Storm EMC (mg/L)**	**Baseflow MC (mg/L)**	**Annual Storm Load (lbs)**	**Annual Baseflow Load (lbs)**	**Annual Total Load (lbs)**	**Yield (lbs/ac/yr)**
Ammonia	WC002	0.053	0.126	107.396	166.669	274.065	0.817
	WC003	0.046	0.052	36.636	18.585	55.22	0.474
	WC004	0.05	0.011	21.634	2.488	24.123	0.619
BOD	WC002	2.574	1.9	5,233.809	2,513.257	7,747.066	23.105
	WC003	2.336	0.7	1,880.401	250.176	2,130.577	18.304
	WC004	1.905	0.2	832.14	45.245	877.385	22.497
Chloride	WC002	330.039	149	670,962.004	197,092.297	868,054.301	2,588.888
	WC003	261.106	183.8	210,149.724	65,689.089	275,838.813	2,369.749
	WC004	187.097	253.1	81,716.703	57,257.998	138,974.7	3,563.454
Nitrate	WC002	0.773	0.0	1,571.415	0.0	1,571.415	4.687
	WC003	0.815	0.0	655.932	0.0	655.932	5.635
	WC004	0.489	0.0	213.447	0.0	213.447	5.473
Nitrate + Nitrite	WC002	0.783	1.84	1,591.433	2,433.891	4,025.324	12.005
	WC003	0.572	1.19	460.179	425.299	885.478	7.607
	WC004	0.444	2.79	194.019	631.173	825.192	21.159
TKN	WC002	0.739	0.38	1503.336	502.651	2005.987	5.983
	WC003	0.847	0.29	681.596	103.644	785.241	6.746
	WC004	0.796	0.25	347.676	56.557	404.233	10.365
Total P	WC002	0.072	0.005	147.277	6.614	153.891	0.459
	WC003	0.059	0.029	47.681	10.364	58.045	0.499
	WC004	0.043	0.002	18.919	0.452	19.372	0.497
Ortho-phosphate	WC002	0.01	0.021	21.325	27.778	49.103	0.146
	WC003	0.017	0.006	13.468	2.109	15.576	0.134
	WC004	0.016	0.012	6.962	2.715	9.676	0.248
TSS	WC002	39.609	1.9	80,524.087	2,513.257	83,037.344	247.651
	WC003	36.899	3.2	29,697.993	1,143.662	30,841.655	264.963
	WC004	20.796	2.3	9,082.964	520.322	9,603.286	246.238
Copper	WC002	6.806	0.420	13.837	0.556	14.392	0.043
	WC003	5.794	0.460	4.663	0.164	4.828	0.041
	WC004	5.388	0.610	2.353	0.138	2.491	0.064
Lead	WC002	0.818	0.0	1.664	0.0	1.664	0.005
	WC003	0.776	0.036	0.624	0.013	0.637	0.005
	WC004	0.624	0.070	0.273	0.016	0.288	0.007
Zinc	WC002	40.601	19.300	82.541	25.529	108.070	0.322
	WC003	42.765	26.100	34.419	9.328	43.747	0.376
	WC004	49.114	22.600	21.451	5.113	26.564	0.681

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APPENDIX E

TOTAL SEASONAL LOADS OF POLLUTANTS AT WHEEL CREEK STUDY STATIONS

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Table E-1. Baseflow and storm flow MCs and EMCs and total seasonal load (July 2018-June 2019)

Sample Year	Season	Station	Storm EMC (mg/L)	Baseflow MC (mg/L)	Seasonal Storm Load (lbs)	Seasonal Baseflow Load (lbs)	Seasonal Total Load (lbs)
Ammonia							
2018	Summer	WC002	0.066	-	61.102	-	61.102
		WC003	0.079	-	25.448	-	25.448
		WC004	0.066	-	13.21	-	13.21
	Fall	WC002	0.033	0.1	14.282	37.332	51.614
		WC003	-	0.1	-	10.592	10.592
		WC004	-	-	-	-	-
2019	Winter	WC002	0.036	-	14.245	-	14.245
		WC003	-	-	-	-	-
		WC004	-	-	-	-	-
	Spring	WC002	0.1	0.32	27.595	82.895	110.49
		WC003	0.103	0.073	12.988	6.532	19.52
		WC004	0.132	0.037	10.639	1.981	12.619
BOD							
2018	Summer	WC002	5.136	-	4756.275	-	4756.275
		WC003	4.138	-	1334.87	-	1334.87
		WC004	3.034	-	604.829	-	604.829
	Fall	WC002	2.747	5.333	1206.649	1991.066	3197.715
		WC003	1.944	1.333	331.22	141.222	472.441
		WC004	1.336	-	89.884	-	89.884
2019	Winter	WC002	0.5	0.667	196.001	213.022	409.023
		WC003	0.5	0.667	93	69.982	162.982
		WC004	0.88	0.667	78.795	43.19	121.985
	Spring	WC002	1.256	0.333	346.134	86.349	432.483
		WC003	2.763	0.333	347.832	29.691	377.522
		WC004	2.37	-	191.209	-	191.209
Chloride							
2018	Summer	WC002	27.393	142	25369.863	52662.232	78032.094
		WC003	42.876	187	13830.602	10740.12	24570.722
		WC004	34.953	294	6966.827	14971.267	21938.094
	Fall	WC002	386.247	125.333	169663.685	46790.048	216453.733
		WC003	403.458	148.333	68750.296	15710.902	84461.198
		WC004	138.283	213.667	9302.016	12072.316	21374.333
2019	Winter	WC002	706.094	195.333	276789.829	62415.59	339205.419
		WC003	526.81	246.333	97986.888	25858.297	123845.185
		WC004	530.023	298.333	47431.512	19327.665	66759.177
	Spring	WC002	70.808	128.667	19512.538	33330.806	52843.344
		WC003	71.281	155.667	8971.989	13865.482	22837.471
		WC004	45.129	233.667	3641.17	12622.189	16263.359

Table E-1. (Continued)

Sample Year	Season	Station	Storm EMC (mg/L)	Baseflow MC (mg/L)	Seasonal Storm Load (lbs)	Seasonal Baseflow Load (lbs)	Seasonal Total Load (lbs)
Nitrate							
2018	Summer	WC002	0.773	-	715.874	-	715.874
		WC003	0.815	-	262.891	-	262.891
		WC004	0.489	-	97.408	-	97.408
	Fall	WC002	-	-	-	-	-
		WC003	-	-	-	-	-
		WC004	-	-	-	-	-
2019	Winter	WC002	-	-	-	-	-
		WC003	-	-	-	-	-
		WC004	-	-	-	-	-
	Spring	WC002	-	-	-	-	-
		WC003	-	-	-	-	-
		WC004	-	-	-	-	-
Nitrate + Nitrite							
2018	Summer	WC002	0.625	1.5	579.028	556.291	1135.32
		WC003	0.608	1.2	196.279	68.921	265.2
		WC004	0.368	3.2	73.343	162.953	236.295
	Fall	WC002	0.565	1.833	248.303	684.429	932.732
		WC003	0.444	1.3	75.619	137.691	213.31
		WC004	0.327	2.5	21.988	141.252	163.24
2019	Winter	WC002	1.132	2.2	443.89	702.974	1146.864
		WC003	0.85	1.3	158.059	136.465	294.524
		WC004	0.682	2.633	61.013	170.602	231.615
	Spring	WC002	0.834	1.6	229.818	414.476	644.294
		WC003	0.385	0.967	48.462	86.103	134.564
		WC004	0.4	3.1	32.295	167.456	199.75
Orthophosphate							
2018	Summer	WC002	0.009	-	8.727	-	8.727
		WC003	0.007	-	2.299	-	2.299
		WC004	0.007	-	1.43	-	1.43
	Fall	WC002	-	-	-	-	-
		WC003	-	-	-	-	-
		WC004	-	-	-	-	-
2019	Winter	WC002	-	0.023	-	7.456	7.456
		WC003	-	0.007	-	0.7	0.7
		WC004	-	0.007	-	0.432	0.432
	Spring	WC002	0.055	0.047	15.041	12.089	27.13
		WC003	0.06	0.013	7.528	1.158	8.686
		WC004	0.057	0.033	4.565	1.801	6.366

Table E-1. (Continued)

Sample Year	Season	Station	Storm EMC (mg/L)	Baseflow MC (mg/L)	Seasonal Storm Load (lbs)	Seasonal Baseflow Load (lbs)	Seasonal Total Load (lbs)
TKN							
2018	Summer	WC002	1.273	-	1178.989	-	1178.989
		WC003	1.277	-	412.084	-	412.084
		WC004	0.919	-	183.135	-	183.135
	Fall	WC002	0.778	0.4	341.584	149.33	490.914
		WC003	0.767	0.467	130.754	49.428	180.181
		WC004	0.508	0.167	34.14	9.417	43.557
2019	Winter	WC002	0.27	0.133	105.845	42.604	148.45
		WC003	0.401	0.1	74.619	10.497	85.116
		WC004	0.637	0.133	57.015	8.638	65.653
	Spring	WC002	0.535	0.733	147.436	189.968	337.404
		WC003	0.941	0.4	118.502	35.629	154.131
		WC004	1.121	0.533	90.421	28.81	119.231
Total Phosphorous							
2018	Summer	WC002	0.186	-	172.337	-	172.337
		WC003	0.13	-	41.963	-	41.963
		WC004	0.082	-	16.433	-	16.433
	Fall	WC002	0.048	-	21.108	-	21.108
		WC003	0.012	-	2.102	-	2.102
		WC004	0.02	-	1.357	-	1.357
2019	Winter	WC002	-	0.003	-	1.065	1.065
		WC003	-	0.097	-	10.147	10.147
		WC004	-	0.007	-	0.432	0.432
	Spring	WC002	0.039	0.013	10.703	3.454	14.157
		WC003	0.095	-	11.901	-	11.901
		WC004	0.071	-	5.7	-	5.7
TSS							
2018	Summer	WC002	108.237	1	100242.655	370.861	100613.516
		WC003	86.232	1	27816.276	57.434	27873.71
		WC004	51.173	14	10199.804	712.917	10912.721
	Fall	WC002	20.398	0.333	8959.993	124.442	9084.435
		WC003	15.204	0.667	2590.794	70.611	2661.404
		WC004	13.144	0.667	884.199	37.667	921.866
2019	Winter	WC002	5.756	2.333	2256.211	745.579	3001.79
		WC003	7.447	0.667	1385.068	69.982	1455.05
		WC004	7.996	1.333	715.576	86.381	801.957
	Spring	WC002	8.482	3.333	2337.5	863.492	3200.992
		WC003	38.713	9	4872.747	801.645	5674.391
		WC004	10.871	1	877.114	54.018	931.132

Table E-2. Baseflow and storm flow MCs and EMCs and total seasonal load (July 2018-June 2019)

Sample Year	Season	Station	Storm EMC (µg/L)	Baseflow MC (µg/L)	Seasonal Storm Load (lbs)	Seasonal Baseflow Load (lbs)	Seasonal Total Load (lbs)
Copper							
2018	Summer	WC002	12.073	0.600	11.181	0.223	11.403
		WC003	12.349	0.500	3.983	0.029	4.012
		WC004	7.505	1.000	1.496	0.051	1.547
	Fall	WC002	6.624	0.233	2.910	0.087	2.997
		WC003	5.276	0.300	0.899	0.032	0.931
		WC004	6.310	0.567	0.424	0.032	0.456
2019	Winter	WC002	5.124	0.400	2.009	0.128	2.137
		WC003	3.107	0.200	0.578	0.021	0.599
		WC004	5.002	0.533	0.448	0.035	0.482
	Spring	WC002	-	0.567	-	0.147	0.147
		WC003	2.444	0.867	0.308	0.077	0.385
		WC004	2.735	0.600	0.221	0.032	0.253
Lead							
2018	Summer	WC002	2.299	-	2.129	-	2.129
		WC003	2.354	-	0.759	-	0.759
		WC004	1.910	0.600	0.381	0.031	0.411
	Fall	WC002	0.566	-	0.249	-	0.249
		WC003	0.206	-	0.035	-	0.035
		WC004	0.367	-	0.025	-	0.025
2019	Winter	WC002	-	-	-	-	-
		WC003	-	-	-	-	-
		WC004	-	-	-	-	-
	Spring	WC002	-	-	-	-	-
		WC003	0.543	0.120	0.068	0.011	0.079
		WC004	0.219	0.033	0.018	0.002	0.020
Zinc							
2018	Summer	WC002	43.281	15.000	40.084	5.563	45.647
		WC003	43.387	18.000	13.996	1.034	15.029
		WC004	41.252	25.000	8.222	1.273	9.495
	Fall	WC002	63.803	21.667	28.026	8.089	36.115
		WC003	43.133	25.000	7.350	2.648	9.998
		WC004	78.190	21.667	5.260	1.224	6.484
2019	Winter	WC002	25.566	24.333	10.022	7.775	17.797
		WC003	25.625	28.333	4.766	2.974	7.741
		WC004	36.374	23.667	3.255	1.533	4.788
	Spring	WC002	18.908	13.333	5.211	3.454	8.665
		WC003	58.914	27.667	7.415	2.464	9.880
		WC004	40.638	21.667	3.279	1.170	4.449

Ecological Condition of Streams in the Wheel Creek Watershed

Harford County, Maryland

Prepared for

Harford County

Department of Public Works

Watershed Protection and Restoration Division

Prepared by

Maryland Department of Natural Resources

Monitoring and Non-Tidal Assessment Division

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The Chesapeake and Atlantic Coastal Bays Trust Fund

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Introduction

Harford County Department of Public Works (DPW) identified the Wheel Creek watershed as a priority restoration opportunity in 2008. In 2009, the County received a Chesapeake and Atlantic Coastal Bays Trust Fund grant to fund stream restorations, stormwater retrofits, and public outreach, along with biological, geomorphological, and water quality monitoring. This report will focus on the biological and physical habitat data collected in this watershed from 2009 - 2017. The Maryland Biological Stream Survey (MBSS), a Maryland Department of Natural Resources (DNR) program, was responsible for collecting and analyzing these data.

The Wheel Creek watershed lies southeast of Bel Air, Maryland, with its headwaters at the Festival Shopping Center on MD Route 24. The watershed drains 435 acres which includes this shopping center, high density residential property, and some forested and agricultural lands. Historically, the watershed has undergone many changes, including a shift from agricultural to urban land cover, with an increase in impervious land cover of 27% over the past three decades (Xian et al. 2011).

Maryland DNR collected ecological data in the Wheel Creek Watershed as part of an agreement between DNR's Resource Assessment Service and Chesapeake and Coastal Services. Data were provided to DPW to assess the effectiveness of several restoration projects, and evaluate ecological lift (if any) in restored areas. In 2009, seven study sites in the Wheel Creek watershed and an eighth control site in an adjacent watershed were selected and sampled prior to construction. These sites were visited three times each year and sampled according to MBSS protocols (Stranko et al. 2015). Due to reduced funding, the number of sites sampled was reduced to the four sites most critical for evaluating the effectiveness of the restoration (ATKI-003-X, ATKI-101-X, ATKI-102-X and LWIN-108-X).

The goal of this sampling program is to evaluate potential effects stream restoration or stormwater retrofits may have on stream ecological conditions. Ecological indicators used to determine such effects may be based on comparisons to reference (a "healthy" stream near the study watershed) and control (usually upstream from the restoration work) sites near the study sites. If the restoration is effective at improving ecological conditions, one would expect to see changes in biological condition over time as illustrated in the Figure 1. The control and study site should mirror one another, then, after construction of the restoration site, conditions should improve in the restored site resulting in similar biological conditions at restored and reference sites. Note that a reference site was not available for this study so comparisons may be made to the control site.

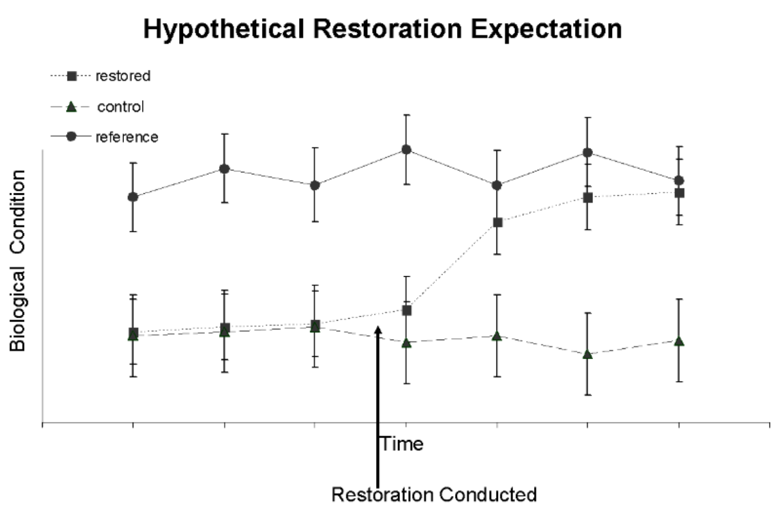

Figure 1 - Hypothetical data from a restored site and reference and control sites

The condition of stream biota depends on several physicochemical, geomorphological, hydraulic, and hydrologic factors (Figure 2). Effective stream and watershed restoration may result in so-called "ecological lift" if the factors beneath the biology are improved and sustained effectively (Harman et al. 2012).

This document will detail the ecological monitoring results performed by the MBSS from 2009 through 2017. It will help determine if improvements in the Wheel Creek Watershed lead to improvements in habitat and biological condition over the years of the project.

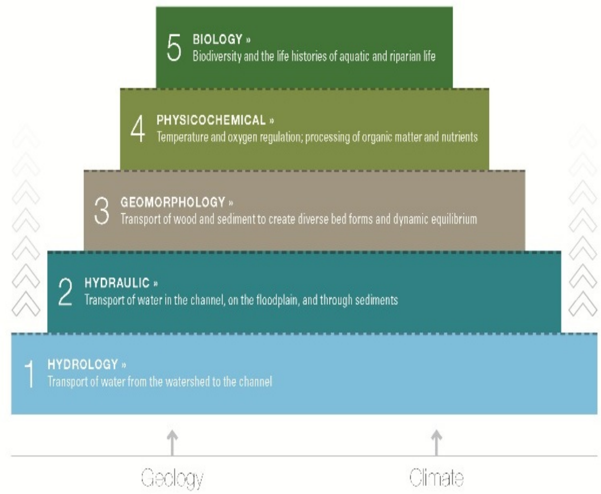

Figure 2 – The Stream Function Pyramid

Study Area and Design

The Wheel Creek watershed contains 2.2 stream miles and lies within the Atkisson Reservoir watershed, a subwatershed of the Bush River Basin. The restoration area includes Wheel Creek and a small unnamed tributary. Several restoration and retrofit projects are being implemented along both waterways. Figure 3 shows an overview of the watershed and the locations of each monitoring and restoration site. Sites ATKI-101-X, ATKI-102-X, ATKI-105-X and ATKI-107-X are on Wheel Creek and sites ATKI-003-X, ATKI-004-X and ATKI-006-X are on an unnamed tributary to Wheel Creek. The control site, LWIN-108-X is in an adjacent watershed on an unnamed tributary to Lower Winters Run. Sampling site and catchment information is in the Appendix.

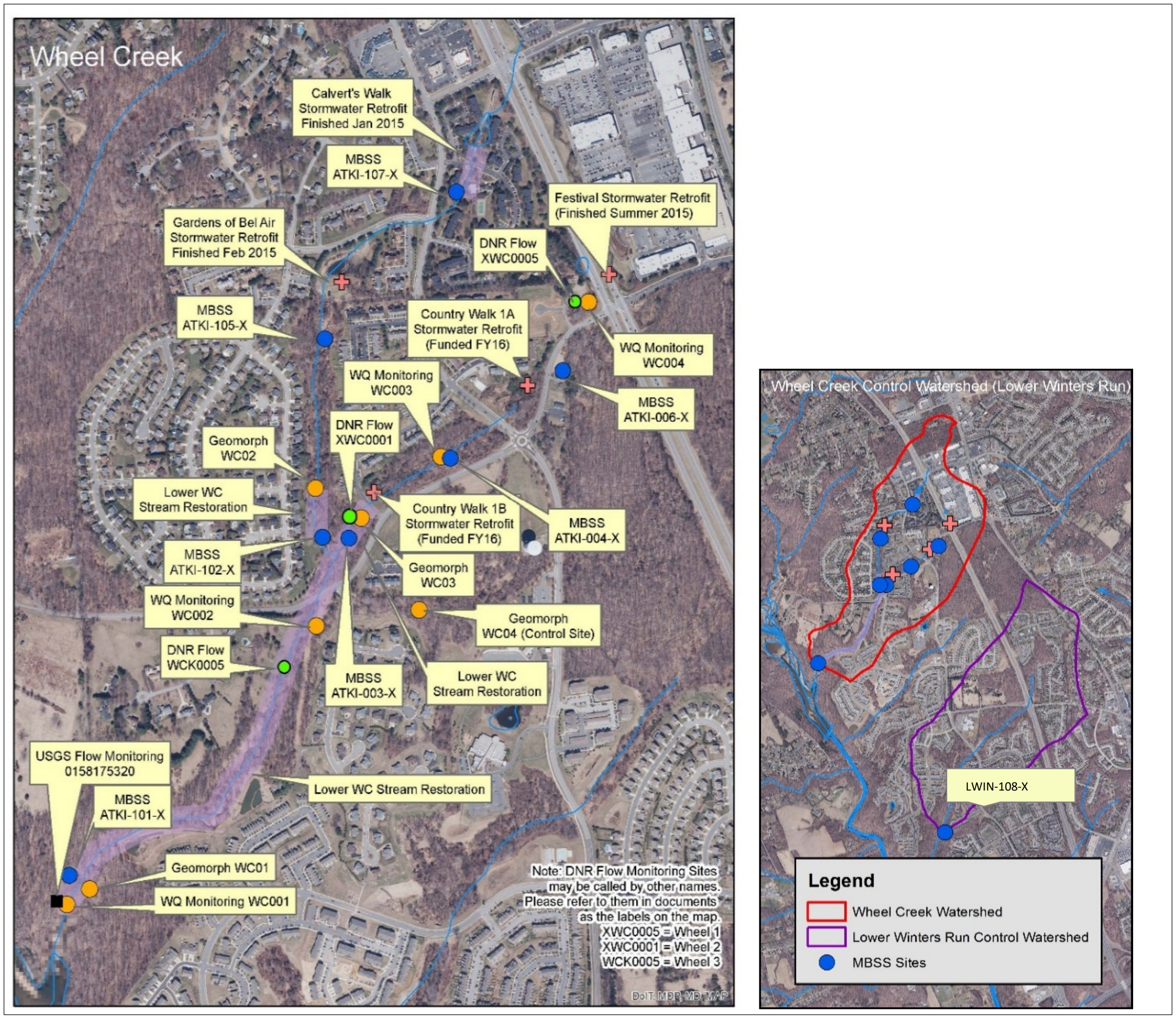

Figure 3 - Wheel Creek Watershed with restoration and retrofit locations and MBSS, USGS and Harford County monitoring sites. The MBSS control site (right) lies within the Lower Winters Run watershed. Site and catchment data are contained in the Appendix.

Name	Project Type	Start Date	Completion Date
Gardens of Bel Air (Pond A)	Stormwater Retrofit	September 2012	December 2012
Calverts Walk (UMS-1)	Stream Restoration	January 2013	April 2013
Festival of Bel Air (Pond C)	Stormwater Retrofit	May 2015	August 2015
Country Walk 1A (Pond D)	Stormwater Retrofit	September 2015	December 2015
MMS-5, B-4, MB-1	Stream Restoration	December 2015	February 2016
Water Quality Facilities	Water Quality Facilities	December 2015	March 2016
Lower Wheel Creek	Stream Restoration	September 2016	July 2017
Country Walk 1B (Pond E)	Stormwater Retrofit	December 2016	July 2017

Table 1 – Wheel Creek Watershed Implementation Schedule

Methods

Monitoring in the Wheel Creek watershed was performed according to MBSS protocols and included benthic macroinvertebrate and fish community sampling and physical habitat assessment. Each 75 m site was visited twice per year for spring and summer sampling (Stranko et al. 2015).

Land Cover Assessment

Upstream catchments for each site were delineated in ArcMap using 1:100,000 scale maps. Land cover was estimated using 2001 and 2011 data contained in the National Land Cover Database (Xian et al. 2011).

Physical Habitat Assessment

MBSS Physical habitat assessments (Stranko et al. 2015) were performed during the summer index period. Habitat parameters were rated visually on a scale of 0-20 (Instream Habitat, Epifaunal Substrate, Velocity/Depth Diversity, Pool Quality) or as a percentage (Embeddedness, Shading). Other habitat measures included discharge (cfs) and Bank Erosion (m^2).

Benthic Macroinvertebrate Sampling and Data Analysis

Benthic macroinvertebrate sampling was conducted during the spring index period (March 1 – April 30) of each year. Each site has been sampled annually since 2009 with the exception of ATKI-107 in 2013 when sampling paused due to in-stream construction at the Calverts Walk (UMS-1) restoration site. Twenty square feet of the best available habitat was sampled using a 500 micron mesh D-net. Samples were field preserved in ethanol and transported to the MDNR laboratory for processing. Each sample was subsampled to approximately 100 organisms and identified lowest practical taxon – primarily genus.

Benthic Indices of Biotic Integrity (BIBI) were calculated for each site. Raw values for six community metrics were calculated and scored based on reference conditions for the Piedmont Physiographic Province (Table 2). Each metric has an expected response to increasing or decreasing perturbation. Metric descriptions can be found in Southerland et al. (2005). BIBI scores and narrative stream health ratings are derived from the average of all metric scores (Table 3).

Metric	Score		
	5	3	1
Total number of taxa	≥25	15-24	<15
Number of EPT taxa	≥11	5-10	<5
Number Ephemeroptera taxa	≥4	2-3	<2
% Intolerant taxa	≥51	12- <51	<12
Percent Chironomidae taxa	≤24	>24-63	>63
Percent clinger taxa	≥74	31- <74	<31

Table 2 – MBSS Benthic Macroinvertebrate IBI metrics and scoring criteria for the Piedmont Physiographic Province

BIBI score	Stream Health Rating

4-5	Good
3-3.9	Fair
2-2.9	Poor
1-1.9	Very Poor

Table 3 – MBSS Benthic Macroinvertebrate IBI score range and stream health rating

Fish Sampling and Data Analysis

Fish were sampled during the summer index period (June 1 – September 30) of each year. The four sites sampled in 2017 have each been sampled annually since 2009. The other sites were sampled annually 2009-2015 with the exception of ATKI-107 in 2013 when sampling paused due to in-stream construction at the Calverts Walk (UMS-1) restoration site. Fish were sampled using block nets and two-pass electrofishing. All collected fish greater than or equal to 30mm in length were identified in the field by MBSS taxonomists, enumerated and released.

As with the BIBIs, fish Indices of Biotic Integrity (FIBI) were calculated for each fish community sample (Southerland et al. 2005). Six fish metrics and their corresponding scores are listed in Table 4. FIBI score ranges and narrative stream health ratings are listed in Table 5.

Metric	Score		
	5	3	1
Fish Abundance	≥1.25	.25-1.24	<0.25
Number of benthic species	≥0.26	0.09-0.25	<0.09
Percent tolerant	≤45	46-68	<68
Biomass	≥8.6	4-8.5	<4
Percent lithophilic spawners	≥61	32-60	>32
Percent generalist, omnivores, and insectivores	≤80	81-99	100

Table 4 – MBSS Fish IBI metrics and scoring criteria for the Piedmont Physiographic Province

FIBI score	Stream Health Rating
4-5	Good
3-3.9	Fair
2-2.9	Poor
1-1.9	Very Poor

Table 5 – MBSS Fish IBI score range and stream health rating

Other Fauna

Crayfish and herpetofauna were sampled at each site and taxa were recorded as a simple count or on a presence/absence basis, respectively. The presence of certain crayfish species may provide insight into stress from competition with exotic species. Some herpetofauna species have strict environmental requirements, so the presence of these species may indicate higher quality habitats.

Results

Site Catchments and Land Cover

Site catchment area for Wheel Creek sites ranged from 393 ac at ATKI-101-X to 50 ac at ATKI-107-X (Appendix). The catchment of LWIN-108-X was 412 ac – the largest of all the sites. It is important to note that MBSS FIBIs are more a reliable indicator of fish community condition for sites with catchments > 300 ac. FIBIs from sites with smaller catchments may be used to evaluate trends but should not be used as a stand-alone indicator of stream health.

Catchments for all Wheel Creek sites (2011 land cover data) contained mostly urban land, with some forest and agricultural land. Forested land cover in each site's catchment ranged from 27.4% at ATKI-107-X to 13.1% at ATKI-102-X. Urban land cover ranged from 82.3% at ATKI-102 to 67.8% at ATKI-101-X. Forested land cover in all Wheel Creek catchments declined between 2001 and 2011, with the greatest loss (10.7%) in ATKI-101-X. The control site's catchment (LWIN-108-X) contained 23.9% forested and 73% urban land. Forested land cover in this site's catchment increased by 0.5% between 2001 and 2011. More accurate land cover data may be provided by DPW.

Physical Habitat

Most physical habitat parameters in both the Wheel Creek sites and the Control site were in the Poor, Marginal or Suboptimal categories (Appendix). Instream Habitat – a measure of fish habitat quality – was rarely rated Good among all years. Instream Habitat was generally rated higher at the Control site. Epifaunal Substrate – a measure of benthic macroinvertebrate habitat suitability – was most often rated Poor, Marginal or Sub-optimal, suggesting that habitat for these organisms was generally lacking.

Biological Communities

Benthic Macroinvertebrates

A total of 122 genera within 52 families and 24 orders were sampled among all sites and all years (Appendix). Among the 4 sites sampled in 2018 (ATKI-003-X, ATKI-101-X, ATKI-102-X and LWIN-108-X) the most abundant genera and their average relative abundances were *Cricotopus* sp. (Diptera, Chironomidae; 15.9%), *Orthocladius* sp. (Diptera, Chironomidae; 15.3%), *Polypedilum* sp. (Diptera, Chironomidae; 10.7%), *Tvetenia* sp. (Diptera, Chironomidae; 7.9%) and *Parametriocnemus* sp. (Diptera, Chironomidae; 6.3%). Two of these five taxa are considered tolerant to pollution, while the other three are considered moderately-tolerant. Fourteen genera (13%) were found at all eight sites during at least one year of sampling.

The presence of intolerant benthic taxa (defined as taxa with tolerance value from 0 to 3) can offer a great deal of insight into overall stream health. In 2018, the number of intolerant taxa ranged from 0 intolerant taxa at ATKI-003-X to 4 intolerant taxa at ATKI-102-X and LWIN-108-X. A total of 24 intolerant taxa have occurred among all sites and all years. A total of 24 intolerant taxa have occurred among all sites and all years.

The cumulative list of intolerant taxa included *Oulimnius sp.* and *Ectopria sp.* (Coleoptera), *Procambarus sp.* (Decapoda), *Potthastia sp., Microspectra sp., Heterotrissocladius sp., Krenosmittia sp., Neoplasta sp., Prosimulium sp., Dicronota sp.* (Diptera), *Maccaffertium sp.* (Ephemeroptera), *Nigronia sp.* (Megaloptera), *Stylogomphus sp.* (Odonota), *Leuctra sp.* and *Amphinemura sp.* (Plecoptera), *Polycentropus sp. ,* *Neureclipsis sp., Nyctiophylax sp., Neophylax sp., Glossosoma sp., Diplectrona sp., Dolophilodes sp., Lepidistoma sp.* (Trichoptera) and *Girardia sp.* (Tricladida).

Fish

Across the four sites sampled in 2018, average species richness ranged from 11.1 at LWIN-108-X to 2.9 at ATKI-107-X. Total taxa richness across all years sampled ranged from 20 at ATKI-101-X to 2 at ATKI-107-X. Two fish species – creek chub and blacknose dace – were found at all sites across all years. Blue Ridge sculpin was found at seven of the eight sites. Forty four percent of the sampled fish species were found at only one site. Six of these were only found at ATKI-101-X and the other five were only found at LWIN-108-X.

Most fish species were considered tolerant or moderately-tolerant to pollution. Intolerant species included blue ridge sculpin, margined madtom, river chub, redbreast sunfish, common shiner and fallfish. The highest number of intolerant fish species (6) was found at LWIN-108-X.

Indices of Biotic Integrity

Across all years, average BIBIs reflected Poor or Very Poor conditions at all sites, including the control site. Scores ranged from 3.0 at LWIN-108-X to 1.0 at ATKI-004-X. Most sites were rated Very Poor by BIBIs. Only LWIN-108-X was rated Fair (BIBI = 3.0 in 2010, 2012, and 2016). No sites were rated Good in any year. BIBI scores changed very little at all eight sites across the years (Figure 4).

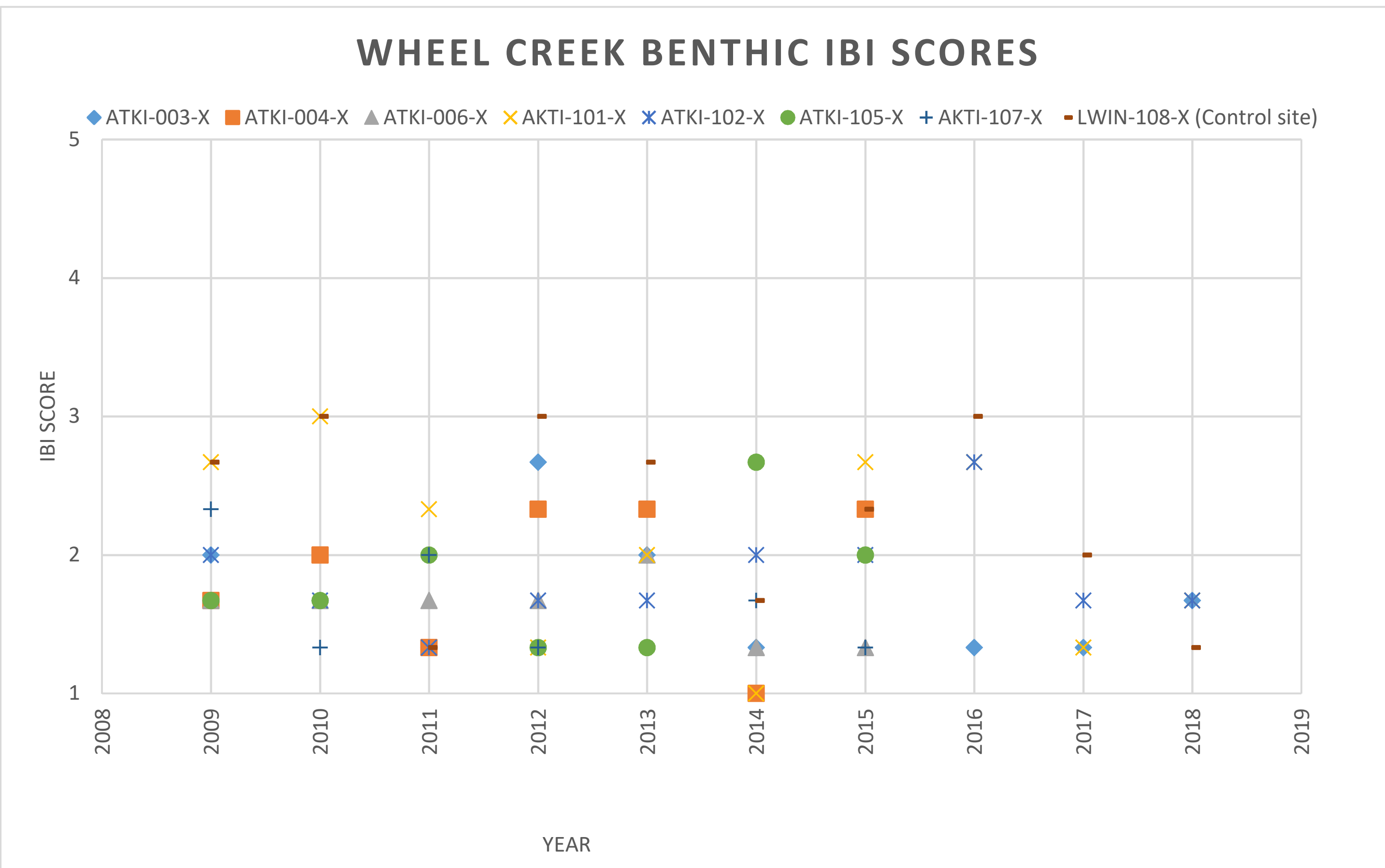

Figure 4 – Benthic IBI scores for Wheel Creek and control sites, 2009 – 2017

In 2018, FIBIs indicated conditions ranging from Good at LWIN-108-X to Fair at ATKI-003-X, ATKI-101-X and ATKI-102-X. FIBI scores changed very little at all 8 sites across the years (Figure 5).

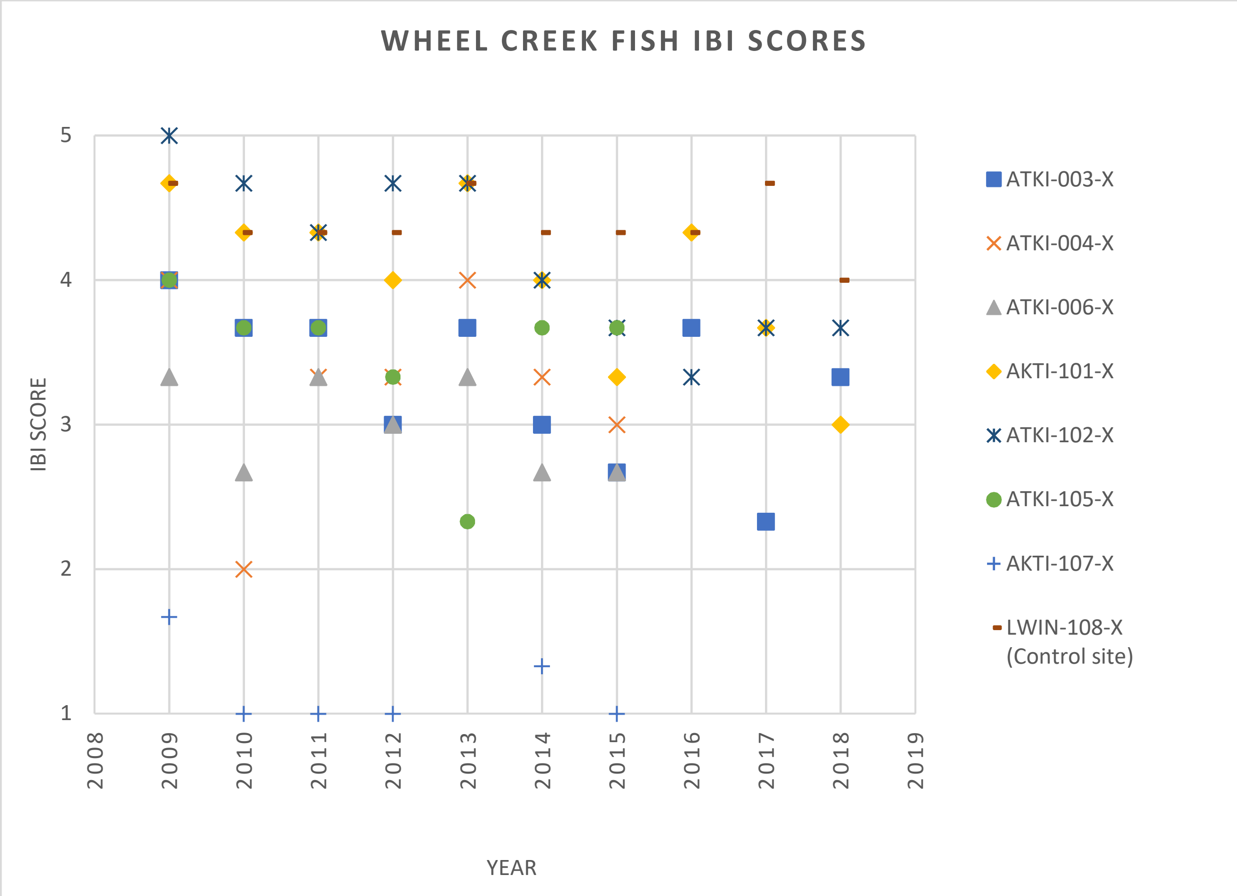

Figure 5 – Fish IBI scores for Wheel Creek and control sites, 2009 – 2017

Crayfish

A total of 8 crayfish species were sampled among all 8 sites. Common species included the common crayfish (*Cambarus bartonii bartonii*), virile crayfish (*Orconectes virilis*), spiny cheek crayfish (*Orconectes limosus*) and unknown Procambarus sp. (*Procambarus sp.*). The virile crayfish – a non-native and invasive species – was found at all sites except ATKI-107-X. This species should be considered a threat to native species as it may expand its range throughout the Wheel Creek Watershed.

Herpetofauna

Reptile and amphibian species counts (presence/absence) ranged from 13 at ATKI-101-X to 5 at ATKI-006-X. Most species are somewhat cosmopolitan and fairly tolerant of disturbed habitats. However, the northern dusky salamander, northern two-lined salamander and northern red salamander are all stream-dwelling species with somewhat strict environmental conditions (with the possible exception of the northern two-lined salamander). Any stream or watershed BMPs that result in stream channel or floodplain (e.g., vernal pool) habitat improvements may directly benefit some herpetofauna species.

Discussion

Streams within the Wheel Creek Watershed are typical of those in urbanized areas of Maryland's Piedmont. At several sites, benthic macroinvertebrate and fish communities – the best indicators of overall stream health - are degraded by multiple stressors resulting from land disturbance, channel alternation and all the stressors associated with upstream impervious surfaces. The presence of some sensitive organisms such as mayflies, stoneflies, fallfish, and northern red salamanders suggests that water quality and habitat at some sites is less degraded than at others. During some sampling years, BIBIs and FIBIs at some sites (e.g., ATKI-102-X and ATKI-101-X) indicate better conditions. Indices during some years were comparable to the control site (LWIN-108-X). These sites may benefit most from restoration projects since they are less degraded than others.

It is likely too early to tell if restoration work conducted in early-mid 2015 and 2016 has had any effect on stream biota or habitat. Further ecological sampling using MBSS protocols will provide valuable insight into the effectiveness of additional restoration work.

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APPENDIX

ATKI-003-X

ATKI-003-X in spring 2018

Coordinates

Latitude	Longitude
39.48825	76.33337

Land Use

Catchment	105 Acres	
Land Cover Type	% of Catchment *2001 NLCD*	% of Catchment *2011 NLCD*
Forest	27.8	22.7
Agriculture	14.1	2.3
Urban	57.5	75.0
Other	0.6	0

Physical Habitat

Physical habitat parameters are scored on a 0 (poor) to 20 (optimal) scale. Score ranges are: 0-5 (poor), 6-10 (marginal), 11-15 (sub-optimal) and 16-20 (optimal)

Parameter	*2009*	*2010*	*2011*	*2012*	*2013*	*2014*	*2015*	*2016*	*2017*	*2018*
Instream habitat (0-20)	9	10	17	12	14	12	12	8	8	14
Epifaunal substrate (0-20)	8	14	16	11	12	13	13	11	11	15
Velocity/Depth Diversity (0-20)	11	11	14	13	13	11	12	11	11	13
Pool Quality (0-20)	11	11	16	12	13	13	12	14	13	11
Riffle Quality (0-20)	8	8	9	12	12	12	11	9	7	13
Shading (%)	85	90	90	80	65	70	80	75	35	45
Embeddedness (%)	40	35	15	60	45	40	35	50	65	45
Discharge (cfs)	0.15	0.13	0.12	1.93	0.06	1.36	0.14	0.02	0.06	0.24
Bank Erosion (m^2)*	60.0	67.8	14	40.8	87.1	66.5	60.0	6.5	3.3	3.7

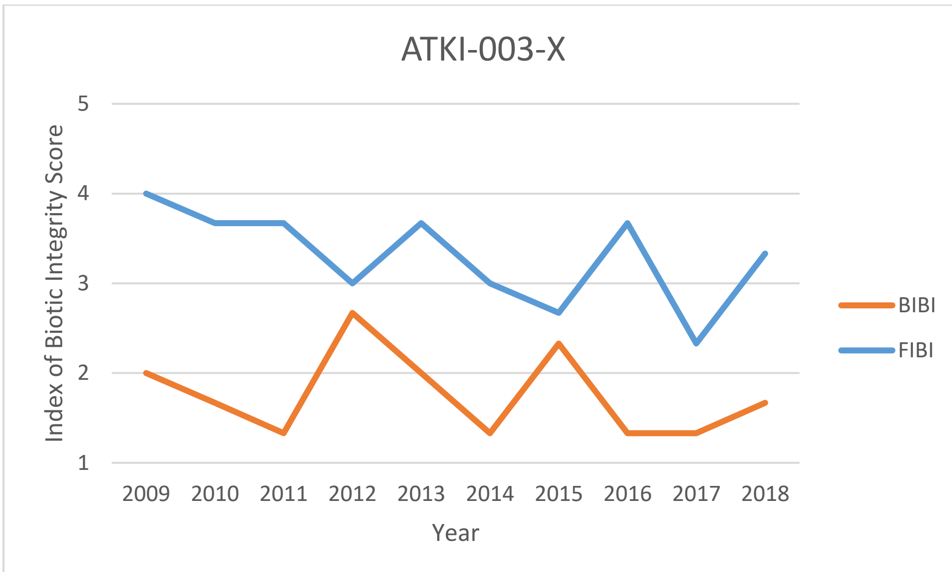
* = Total area of eroded stream banks (sum of left and right banks)

Biology

Indexes of Biotic Integrity.

Metric	*2009*	*2010*	*2011*	*2012*	*2013*	*2014*	*2015*	*2016*	*2017*	*2018*
BIBI	2.00	1.67	1.33	2.67	2.00	1.33	2.33	1.33	1.33	1.67
FIBI	4.00	3.67	3.67	3.00	3.67	3.00	2.67	3.67	2.33	3.33

IBI scores less than 2 are rated very poor, 2 to 2.9 are rated poor, 3 to 3.9 are rated fair, and 4 to 5 are rated good.



Fish species collected and their annual abundance.

Species	*Tolerance*	*2009*	*2010*	*2011*	*2012*	*2013*	*2014*	*2015*	*2016*	*2017*	*2018*
Blacknose dace	T	97	44	52	73	51	64	61	327	126	123
Blue ridge sculpin	I	89	62	37	25	25	32	20	45	0	11
Creek chub	T	231	99	106	87	120	60	61	239	133	83

Tolerance values are represented as I, M, or T. Intolerant species are represented by I, moderately tolerant species are represented by M, and tolerant species are represented by T.

Crayfish species collected and their annual abundance.

Species	*2009*	*2010*	*2011*	*2012*	*2013*	*2014*	*2015*	*2016*	*2017*	*2018*
Virile crayfish (Orconectes virilis)	*3*	*4*	*2*	*28*	*7*	*7*	*6*	*16*	*17*	*12*
Unknown Procambarus (Procambarus sp.)	*0*	*0*	*0*	*1*	*0*	*0*	*0*	*0*	*0*	*0*

Herpetofauna (P) presence or (A) absence.

Order (Common)	*Species*	*2009*	*2010*	*2011*	*2012*	*2013*	*2014*	*2015*	*2016*	*2017*	*2018*
Anura (Frogs and Toads)	*American Bullfrog*	*A*	*A*	*A*	*A*	*A*	*A*	*A*	*A*	*A*	*P*
	Cope's gray treefrog	*A*	*A*	*A*	*P*	*P*	*A*	*A*	*A*	*P*	*A*
	Northern green frog	*A*	*A*	*A*	*P*	*P*	*P*	*P*	*P*	*P*	*P*
	Northern spring peeper	*A*	*A*	*A*	*A*	*A*	*A*	*P*	*A*	*A*	*A*
	Pickerel frog	*A*	*A*	*P*	*P*	*P*	*A*	*A*	*P*	*P*	*A*
Caudata (Salamanders and Newts)	*Eastern red-backed salamander*	*P*	*A*	*A*	*A*	*A*	*A*	*A*	*A*	*A*	*A*
	Northern dusky salamander	*A*	*A*	*A*	*P*	*A*	*A*	*A*	*A*	*A*	*A*
	Northern red salamander	*P*	*A*	*P*	*A*	*A*	*A*	*P*	*A*	*A*	*A*
	Northern two-lined salamander	*P*	*A*	*P*	*P*	*P*	*P*	*P*	*P*	*A*	*P*

Benthic macroinvertebrates collected and their annual relative abundance. (genera (RA)) = (number of genera (percent relative abundance)).

Phylum	Order	Family	Genus	Tolerance	2009 RA	2010 RA	2011 RA	2012 RA	2013 RA	2014 RA	2015 RA	2016 RA	2017 RA	2018 RA
Annelida	*Haplotaxida*	*Enchytraeidae*	*n/a*	*T*	---	---	---	---	**0.9*	---	---	---	---	---
		Naididae	*n/a*	*T*	---	---	**1.0*	---	---	---	---	---	---	---
	Lumbriculida	*Lumbriculidae*	*n/a*	*M*	---	**0.8*	---	---	---	---	---	---	---	---
	Tubificida	*Tubificidae*	*n/a*	*T*	---	**1.7*	---	---	---	---	---	---	---	---
			Spirosperma	*M*	---	---	---	*0.9*	---	---	---	---	---	---
Arthropoda	*Amphipoda*	*Crangonyctidae*	*Stygobromus*	*M*	*1.8*	---	---	---	---	---	---	---	---	---
	Coleoptera	*Elmidae*	*Ancyronyx*	*T*	---	---	---	---	---	*0.9*	---	---	---	---
			Stenelmis	*T*	*6.4*	*5*	*4.8*	*15.8*	*18.1*	*8.8*	*18.4*	*9.1*	*7.3*	*2.3*
		Dytiscidae	*Neoporus*	*M*	---	*0.8*	---	---	---	---	---	---	---	---
		Psephenidae	*Ectopria*	*I*	---	---	---	*0.9*	---	---	---	---	---	---
	Collembola	*Isotomidae*	*Isotomurus*	*M*	---	---	---	---	---	*0.9*	---	---	---	---
		n/a	*n/a*	*M*	---	---	---	---	---	---	---	---	---	*3.1
	Diptera	*Ceratopogonidae*	*n/a*	*M*	**1.8*	---	**1.0*	---	---	---	---	---	---	---
		Chironomidae	*Ablabesmyia*	*T*	---	*0.8*	*1*	---	---	---	*1.6*	*0.8*	---	---
			Brillia	*T*	---	---	---	---	---	---	---	*1.7*	---	---
			Chaetocladius	*T*	*12.8*	---	---	*2.6*	---	---	---	*1.7*	*0.8*	---
			Chironomini	*M*	---	**0.8*	---	---	---	---	---	---	---	---
			Chironomus	*M*	---	---	---	*0.9*	---	---	---	*11.6*	---	---
			Corynoneura	*M*	---	*0.8*	---	---	*0.9*	---	---	---	---	---
			Cricotopus	*T*	---	---	---	---	---	---	---	---	---	14
			Cryptochironomus	*T*	---	---	---	---	---	---	*0.8*	---	---	---
			Diamesa	*T*	---	---	---	---	---	---	*0.8*	*0.8*	---	1.6

Phylum	Order	Family	Genus	Tolerance	2009 RA	2010 RA	2011 RA	2012 RA	2013 RA	2014 RA	2015 RA	2016 RA	2017 RA	2018 RA
Arthropoda	*Diptera*	*Chironomidae*	*Diamesinae*	*T*	---	---	---	---	---	---	---	3.3	---	---
			Dicrotendipes	*T*	---	---	---	---	---	---	1.6	---	---	---
			Eukiefferiella	*M*	---	6.7	---	6.1	---	---	---	0.8	---	0.8
			Heterotrissocladius	*I*	---	0.8	---	---	---	---	---	---	---	---
			Hydrobaenus	*T*	0.9	---	16.3	0.9	11.2	2.6	---	1.7	---	---
			Krenosmittia	*I*	---	---	---	---	---	---	2.4	---	---	---
			Microtendipes	*T*	---	---	---	---	---	---	---	---	---	0.8
			Micropsectra	*I*	1.8	20	---	10.5	---	0.9	---	4.1	---	---
			Orthocladiinae	*T*	*0.9	*0.8	*1.0	*3.5	*1.7	*2.6	*3.2	*2.5	---	2.3
			Orthocladius	*T*	19.3	25.8	58.7	16.7	19	50.9	22.2	30.6	21.1	7.8
			Paramerina	*M*	---	---	---	---	---	---	0.8	---	---	---
			Parametriocnemus	*M*	1.8	---	---	0.9	---	4.4	---	---	21.1	14.7
			Paraphaenocladius	*M*	0.9	---	---	---	---	---	---	---	---	---
			Paratanytarsus	*T*	---	---	1	---	3.4	---	---	---	---	---
			Paratendipes	*M*	---	---	---	0.9	---	---	---	---	---	---
			Phaenopsectra	*T*	---	---	---		0.9	0.9	---	---	---	---
			Polypedilum	*M*	7.3	13.3	2.8	5.3	---	---	1.6	8.3	30.9	8.5
			Rheocricotopus	*M*	---	---	---	---	---	---	---	4.1	---	---
			Rheotanytarsus	*T*	4.6	---	1.9	2.6	---	0.9	14.4	---	3.3	10.1
			Stenochironomus	*T*	---	---	---	---	---	---	0.8	---	0.8	---

Phylum	Order	Family	Genus	Tolerance	2009 RA	2010 RA	2011 RA	2012 RA	2013 RA	2014 RA	2015 RA	2016 RA	2017 RA	2018 RA
Arthropoda	*Diptera*	*Chironomidae*	*Sympotthastia*	*T*	---	---	---	---	*4.3*	*8.8*	---	---	---	---
			Tanypodinae	*T*	---	---	---	---	---	---	**0.8*	**0.8*	**0.8*	---
			Tanytarsini	*M*	---	---	---	**0.9*	---	---	**3.1*	---	**0.8*	---
			Tanytarsus	*M*	*2.8*	---	*1.9*	---	---	*0.9*	---	*0.8*	*0.8*	---
			Thienemanniella	*M*	---	*2.5*	---	---	---	---	---	---	---	3.9
			Thienemannimyia Group	*T*	**1.8*	**1.7*	**2.9*	**0.9*	**2.6*	**0.9*	---	**1.6*	**4.1*	5.4
			Tvetenia	*M*	---	*3.3*	---	*2.6*	*2.6*	*0.9*	---	---	---	7.8
			Zavrelimyia	*M*	---	*1.7*	---	---	*2.6*	---	*0.8*	*0.8*	---	---
		Empididae	*n/a*	*T*	**0.9*	**2.5*	---	**5.3*	---	---	---	---	**0.8*	---
			Clinocera	*T*	*5.5*	---	---	---	*2.6*	*2.6*	*2.4*	---	*0.8*	---
			Hemerodromia	*T*	---	*0.8*	---	---	---	---	---	---	---	---
			Neoplasta	*I*	---	---	---	---	---	---	*0.8*	---	---	---
		Simuliidae	*Prosimulium*	*I*	---	---	---	*0.9*	---	---	---	---	---	---
			Simulium	*M*	*1.8*	*0.8*	---	*3.5*	---	---	*3.2*	*2.5*	---	0.8
		Tipulidae	*Antocha*	*T*	---	---	---	---	---	---	*1.6*	---	---	---
			Tipula	*M*	*2.8*	---	---	---	*0.9*	*0.9*	---	*0.8*	---	---
	Ephemeroptera	*Ephemerellidae*	*Eurylophella*	*M*	---	---	---	---	*0.9*	---	---	---	---	---
		Siphlonuridae	*Siphlonurus*	*T*	---	---	---	---	---	---	---	*0.8*	---	---
	Hemiptera	*Veliidae*	*Microvelia*	*M*	---	---	---	---	*0.9*	---	---	---	---	---
	Odonata	*Calopterygidae*	*Calopteryx*	*T*	*0.9*	*0.8*	---	---	*1.7*	---	*0.8*	---	---	---
		Coenagrionidae	*Argia*	*T*	---	*0.8*	---	---	---	---	---	---	---	---
		Gomphidae	*Stylogomphus*	*I*	---	---	---	*1.8*	---	---	---	---	---	---
		Libellulidae	*Pachydiplax*	*T*	---	*0.8*	---	---	---	---	---	---	---	---

Phylum	Order	Family	Genus	Tolerance	2009 RA	2010 RA	2011 RA	2012 RA	2013 RA	2014 RA	2015 RA	2016 RA	2017 RA	2018 RA
Arthropoda	*Plecoptera*	*Nemouridae*	*Amphinemura*	*I*	---	---	---	*0.9*	---	---	---	---	---	---
	Trichoptera	*Glossosomatidae*	*Glossosoma*	*I*	---	---	---	---	---	---	*0.8*	---	---	---
		Hydropsychidae	*n/a*	*T*	---	---	---	**1.8*	---	---	---	---	---	---
			Cheumatopsyche	*T*	*1.8*	---	*2.9*	*3.5*	*3.4*	*1.8*	*2.4*	---	*5.7*	*4.7*
			Diplectrona	*I*	*7.3*	---	---	*2.6*	---	---	*0.8*	*0.8*	*0.8*	---
			Hydropsyche	*T*	*5.5*	*1.7*	*1*	*5.3*	*1.7*	*1.8*	*2.4*	*0.8*	---	*1.6*
		Philopotamidae	*Chimarra*	*M*	*8.3*	*1.7*	*1*	*1.8*	*19*	*7*	*10.4*	*8.2*	---	*7.8*
		Psychomyiidae	*Lype*	*M*	---	---	---	---	---	---	*0.8*	---	---	
Mollusca	*Basommatophora*	*Ancylidae*	*Ferrissia*	*T*	---	---	---	---	---	---	---	---	---	*0.8*
		Physidae	*Physa*	*T*	---	---	---	---	---	*0.9*	---	*0.8*	---	---

Tolerance values are represented as I, M, or T. Intolerant taxa with tolerance values from 0 to 3 are represented by I. Moderately tolerant taxa with tolerance values from 3.1 to 6.9 are represented by M. Tolerant genera with tolerance values from 7 to 10 are represented by T.

* Taxa not identified to genus.

ATKI-004-X


ATKI-004-X in spring 2015

Coordinates

Latitude	*Longitude*
39.48969	76.33089

Land Use

Catchment	90 Acres	
Land Cover Type	% of Catchment *2001 NLCD*	% of Catchment *2011 NLCD*
Forest	24.9	21.5
Agriculture	13.8	2.2
Urban	61.1	76.3
Other	0.3	0

Physical Habitat

Physical habitat parameters are scored on a 0 (poor) to 20 (optimal) scale. Score ranges are: 0-5 (poor), 6-10 (marginal), 11-15 (sub-optimal) and 16-20 (optimal)

Parameter	*2009*	*2010*	*2011*	*2012*	*2013*	*2014*	*2015*
Instream habitat (0-20)	16	9	16	15	11	13	12
Epifaunal substrate (0-20)	13	12	17	13	9	14	11
Velocity/Depth Diversity (0-20)	11	11	15	13	8	13	11
Pool Quality (0-20)	9	11	15	15	8	11	11
Riffle Quality (0-20)	14	7	15	11	8	14	11
Shading (%)	80	85	85	80	70	80	85
Embeddedness (%)	25	35	20	55	45	20	20
Discharge (cfs)	0.08	0.08	0.23	0.15	0.02	2.24	0.21
Bank Erosion (m^2)*	104.5	109.8	16.8	130.4	85.4	33.1	115.0

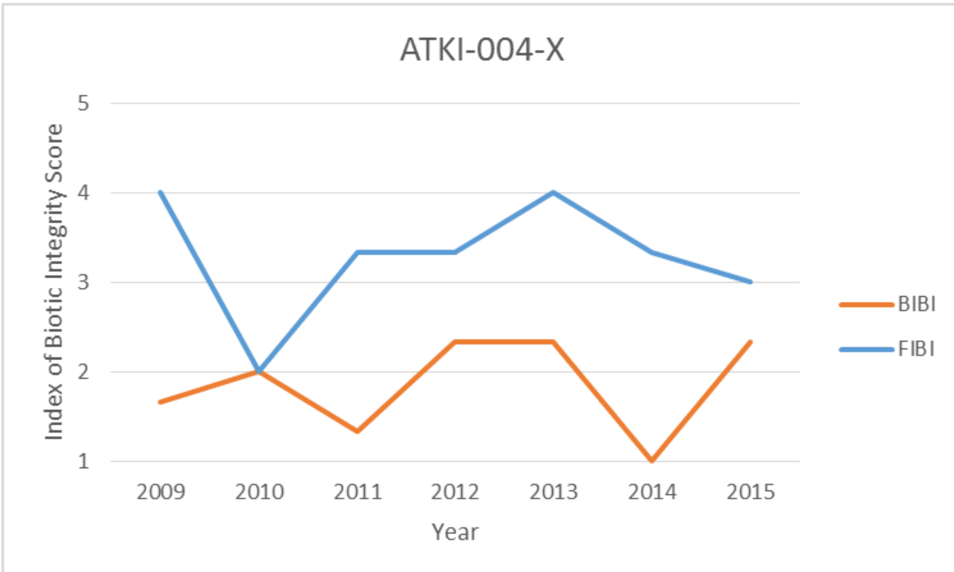
* = Total area of eroded stream banks (sum of left and right banks)

Biology

Indexes of Biotic Integrity.

Metric	*2009*	*2010*	*2011*	*2012*	*2013*	*2014*	*2015*
BIBI	1.67	2.00	1.33	2.33	2.33	1.00	2.33
FIBI	4.00	2.00	3.33	3.33	4.00	3.33	3.00

IBI scores less than 2 are rated very poor, 2 to 2.9 are rated poor, 3 to 3.9 are rated fair, and 4 to 5 are rated good.



Fish species collected and their annual abundance.

Species	*Tolerance*	*2009*	*2010*	*2011*	*2012*	*2013*	*2014*	*2015*
Blacknose dace	T	2	24	55	53	86	58	117
Blue ridge sculpin	I	38	0	14	15	50	37	24
Creek chub	T	7	71	102	69	147	99	61

Tolerance values are represented as I, M, or T. Intolerant species are represented by I, moderately tolerant species are represented by M, and tolerant species are represented by T.

Crayfish species collected and their annual abundance.

Species	*2009*	*2010*	*2011*	*2012*	*2013*	*2014*	*2015*
Virile crayfish *(Orconectes virilis*)	14	9	7	19	3	8	8

Herpetofauna (P) presence or (A) absence.

Order (Common)	*Species*	*2009*	*2010*	*2011*	*2012*	*2013*	*2014*	*2015*
Anura (Frogs and Toads)	*Eastern American toad*	A	P	A	A	A	A	A
	Northern green frog	A	A	P	P	P	A	P
	Pickerel frog	A	A	A	A	A	P	A
Caudata (Salamanders and Newts)	*Northern dusky salamander*	P	P	P	P	A	A	A
	Northern red salamander	P	A	A	P	A	A	A
	Northern two-lined salamander	P	P	P	P	P	P	P
	Psuedotriton sp.	A	P	A	A	A	A	A

Benthic macroinvertebrates collected and their annual relative abundance. (genera (RA)) = (number of genera (percent relative abundance)).

Phylum	*Order*	*Family*	*Genus*	*Tolerance*	*2009 RA*	*2010 RA*	*2011 RA*	*2012 RA*	*2013 RA*	*2014 RA*	*2015 RA*
Annelida	Haplotaxida	Naididae	*n/a*	T	---	---	*2.1	---	---	---	---
	Lumbriculida	Lumbriculidae	*n/a*	M	*1.9	---	---	---	---	---	---
	Tubificida	Tubificidae	*n/a*	T	---	*1.6	---	---	---	---	---
			Spirosperma	M	---	---	0.9	---	---	---	---
Arthropoda	Amphipoda	Crangonyctidae	*Stygobromus*	M	---	0.8	---	---	---	---	---
	Coleoptera	Dytiscidae	*Neoporus*	M	---	---	1.1	---	---	---	---
		Elmidae	*Stenelmis*	T	0.9	0.8	6.4	0.9	7	1.7	5
		Hydrophilidae	*Hydrobius*	M	0.9	---	---	---	---	---	---
	Collembola	Isotomidae	*Isotomurus*	M	---	---	---	1.9	0.9	---	---
	Diptera	Ceratopogonidae	*Dasyhelea*	M	---	---	2.1	---	---	---	---
		Chironomidae	*n/a*	M	*0.9	---	---	---	---	---	---
			Ablabesmyia	T	0.9	---	---	---	---	---	2.5
			Chaetocladius	T	4.7	---	---	4.7	---	---	---
			Corynoneura	M	---	0.8	1.1	---	---	---	---
			Cricotopus	T	---	---	---	---	3.5	---	---
			Diamesa	T	---	---	1.1	---	---	---	---
			Diamesinae	T	---	---	---	---	*0.9	*1.7	---
			Dicrotendipes	T	0.9	---	1.1	---	---	---	---
			Eukiefferiella	M	---	18.3	---	13.2	---	0.9	---
			Micropsectra	I	0.9	22.2	---	3.8	---	---	---
			Orthocladiinae	T	*4.7	*0.8	*4.3	---	*1.7	*1.7	*4.2
			Orthocladius	T	40.6	8.7	44.7	10.4	40.9	45.3	33.3
			Parametriocnemus	M	3.8	---	---	---	---	0.9	0.8
			Paraphaenocladius	M	---	3.2	---	3.8	---	---	---
			Paratanytarsus	T	0.9	---	---	---	---	---	---
			Phaenopsectra	T	---	---	1.1	---	---	---	---
			Polypedilum	M	1.9	11.9	2.1	7.5	---	---	0.8

Phylum	Order	Family	Genus	Tolerance	2009 RA	2010 RA	2011 RA	2012 RA	2013 RA	2014 RA	2015 RA
			Potthastia	I	---	---	---	0.9	---	---	---
			Rheocricotopus	M	---	0.8	---	---	---	---	---
Arthropoda	Diptera	Chironomidae	*Rheotanytarsus*	T	1.9	---	3.2	3.8	0.9	---	6.7
			Sympotthastia	T	---	---	1.1	---	3.5	17.1	---
			Tanypodinae	T	*0.9	---	---	---	---	---	*1.7
			Tanytarsini	M	---	---	---	*0.9	---	---	---
			Tanytarsus	M	0.9	---	1.1	14.2	0.9	---	1.7
			Thienemanniella	M	---	2.4	---	---	---	0.9	---
			Thienemannimyia Group	T	*6.6	*1.6	*8.5	*1.9	*6.1	*0.9	*5.0
			Tvetenia	M	---	0.8	---	7.5	3.5	3.4	---
			Zavrelimyia	M	---	0.8	2.1	---	---	---	1.7
		Empididae	*Clinocera*	T	0.9	---	---	---	---	0.9	---
			Hemerodromia	T	---	0.8	1.1	---	---	---	---
		Simuliidae	*Simulium*	M	---	1.6	---	---	---	---	5
		Tipulidae	*Antocha*	T	0.9	0.8	---	0.9	---	---	---
			Tipula	M	3.8	---	1.1	---	0.9	0.9	0.8
	Ephemeroptera	Baetidae	*Baetis*	M	---	0.8	---	---	---	---	---
		Ephemerellidae	*Eurylophella*	M	---	---	---	---	0.9	---	---
	Hemiptera	Veliidae	*Microvelia*	M	---	---	---	---	---	---	0.8
	Megaloptera	Corydalidae	*Nigronia*	I	---	---	---	---	---	---	0.8
	Odonata	Aeshnidae	*Aeshna*	M	0.9	---	---	---	---	---	---
		Calopterygidae	*Calopteryx*	T	0.9	---	2.1	---	1.7	---	1.7
		Gomphidae	*n/a*	I	---	---	*1.1	---	---	---	---
	Plecoptera	Nemouridae	*Amphinemura*	I	---	0.8	---	3.8	---	---	3.3
	Trichoptera	Hydropsychidae	*Cheumatopsyche*	T	0.9	4	6.4	4.7	5.2	3.4	---
			Diplectrona	I	11.3	---	---	3.8	3.5	6	0.8
			Hydropsyche	T	---	1.6	1.1	1.9	2.6	4.3	9.2
		Lepidostomatidae	*Lepidostoma*	I	---	---	---	---	---	---	0.8
		Limnephilidae	*Ironoquia*	M	---	---	---	---	---	---	0.8
		Philopotamidae	*n/a*	I	---	---	---	---	---	---	*0.8
			Chimarra	M	4.7	1.6	3.2	6.6	13.9	10.3	10
			Dolophilodes	I	---	4	---	0.9	---	---	---
		Polycentropodidae	*Nyctiophylax*	I	0.9	---	---	---	---	---	---
Mollusca	Basommatophora	Physidae	*Physa*	T	---	3.2	---	---	0.9	---	1.7

Tolerance values are represented as I, M, or T. Intolerant taxa with tolerance values from 0 to 3 are represented by I. Moderately tolerant taxa with tolerance values from 3.1 to 6.9 are represented by M. Tolerant genera with tolerance values from 7 to 10 are represented by T.

* Taxa not identified to genus.

ATKI-006-X

ATKI-006-X in spring 2015

Coordinates

Latitude	*Longitude*
39.49126	76.32814

Land Use

Catchment	57 Acres	
Land Cover Type	% of Catchment *2001 NLCD*	% of Catchment *2011 NLCD*
Forest	22.0	18.9
Agriculture	5.8	0
Urban	72.2	81.1
Other	0	0

Physical Habitat

Physical habitat parameters are scored on a 0 (poor) to 20 (optimal) scale. Score ranges are: 0-5 (poor), 6-10 (marginal), 11-15 (sub-optimal) and 16-20 (optimal).

Parameter	*2009*	*2010*	*2011*	*2012*	*2013*	*2014*	*2015*
Instream habitat (0-20)	9	7	14	10	7	8	6
Epifaunal substrate (0-20)	6	6	13	11	6	7	5
Velocity/Depth Diversity (0-20)	7	7	9	3	7	8	11
Pool Quality (0-20)	8	8	9	10	7	9	11
Riffle Quality (0-20)	8	7	8	6	9	10	6
Shading (%)	65	60	95	95	65	70	80
Embeddedness (%)	20	20	20	60	35	40	30
Discharge (cfs)	0.02	0.05	0.09	0.01	0.02	0.04	0.10
Bank Erosion (m^2)*	68.5	86.2	18.4	69.0	100.8	83.3	20.5

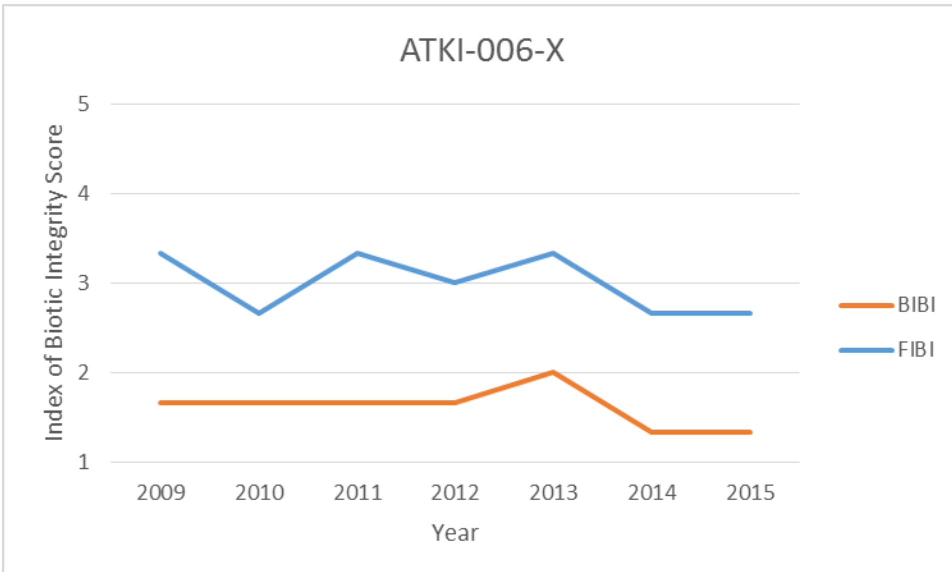
* = Total area of eroded stream banks (sum of left and right banks)

Biology

Indexes of Biotic Integrity.

Metric	*2009*	*2010*	*2011*	*2012*	*2013*	*2014*	*2015*
BIBI	1.67	1.67	1.67	1.67	2.00	1.33	1.33
FIBI	3.33	2.67	3.33	3.00	3.33	2.67	2.67

IBI scores less than 2 are rated very poor, 2 to 2.9 are rated poor, 3 to 3.9 are rated fair, and 4 to 5 are rated good.



Fish species collected and their annual abundance.

Species	*Tolerance*	*2009*	*2010*	*2011*	*2012*	*2013*	*2014*	*2015*
Blacknose dace	T	21	40	20	46	32	51	15
Blue ridge sculpin	I	5	0	2	2	4	0	1
Creek chub	T	98	112	143	72	140	112	78

Tolerance values are represented as I, M, or T. Intolerant species are represented by I, moderately tolerant species are represented by M, and tolerant species are represented by T.

Crayfish species collected and their annual abundance.

Species	*2009*	*2010*	*2011*	*2012*	*2013*	*2014*	*2015*
Devil crawfish *(Cambarus diogenes)*	1	0	0	0	0	0	0
Virile crayfish *(Orconectes virilis)*	1	3	0	10	14	5	5

Herpetofauna (P) presence or (A) absence.

Order (Common)	*Species*	*2009*	*2010*	*2011*	*2012*	*2013*	*2014*	*2015*
Anura (Frogs and Toads)	*Gray treefrog*	A	A	A	P	A	A	A
	Northern green frog	P	P	A	P	A	A	P
	Pickerel frog	P	P	A	A	A	A	A
Caudata (Salamanders and Newts)	*Northern dusky salamander*	A	P	A	P	P	P	P
Squamata (Snakes and Lizards)	*Northern watersnake*	A	A	P	A	A	A	A

Benthic macroinvertebrates collected and their annual relative abundance. (genera (RA)) = (number of genera (percent relative abundance)).

Phylum	*Order*	*Family*	*Genus*	*Tolerance*	*2009 RA*	*2010 RA*	*2011 RA*	*2012 RA*	*2013 RA*	*2014 RA*	*2015 RA*
Annelida	Haplotaxida	Enchytraeidae	*n/a*	T	---	---	*1.8	---	---	---	---
		Naididae	*n/a*	T	---	*0.8	---	*0.8	*0.9	---	---
	Lumbriculida	Lumbriculidae	*n/a*	M	*2.2	---	*10..9	*6.7	*1.7	*2.2	*4.8
	Tubificida	Tubificidae	*n/a*	T	*1.1	*11.7	*12.7	*3.3	---	---	*1.6
Arthropoda	Coleoptera	Dryopidae	*Helichus*	M	---	---	---	---	---	---	0.8
		Elmidae	*Stenelmis*	T	2.2	---	---	0.8	1.7	7.8	12.1
	Diptera	Chironomidae	*Chaetocladius*	T	---	---	---	---	---	---	3.2
			Chironomus	M	---	0.8	---	---	---	---	---
			Corynoneura	M	---	2.5	---	---	---	---	---
			Dicrotendipes	T	---	---	---	---	---	---	0.8
			Eukiefferiella	M	---	7.5	---	23.3	1.7	---	---
			Hydrobaenus	T	---	---	1.8	---	---	---	---
			Krenosmittia	I	---	---	---	---	---	---	0.8
			Limnophyes	T	---	---	---	3.3	---	1.1	---
			Micropsectra	I	1.1	11.7	---	15.8	---	---	---
			Natarsia	M	---	---	1.8	---	---	---	---
			Orthocladiinae	T	*6.5	*8.3	---	*2.5	*1.7	---	*4.0
			Orthocladius	T	22.6	33.3	9.1	21.7	6	14.4	42.7
			Polypedilum	M	2.2	5.8	---	1.7	---	---	---
			Potthastia	I	---	---	---	5	---	---	---
			Rheotanytarsus	T	---	---	---	---	0.9	---	0.8
			Tanypodinae	T	*3.2	*1.7	---	---	---	---	---
			Thienemannimyia Group	T	*16.1	*5.8	*12.7	*1.7	*17.9	*30.0	*14.5
			Tvetenia	M	---	0.8	---	0.8	0.9	2.2	---
			Zavrelimyia	M	---	---	---	1.7	0.9	1.1	---
		Empididae	*Hemerodromia*	T	1.1	0.8	---	---	---	---	---

Phylum	*Order*	*Family*	*Genus*	*Tolerance*	*2009 RA*	*2010 RA*	*2011 RA*	*2012 RA*	*2013 RA*	*2014 RA*	*2015 RA*
Arthopoda	Diptera	Simuliidae	*Simulium*	M	---	2.5	---	---	---	---	---
		Tipulidae	*Antocha*	T	---	0.8	1.8	---	1.7	4.4	0.8
			Tipula	M	---	---	1.8	0.8	5.1	6.7	0.8
	Hemiptera	Belostomatidae	*Belostoma*	T	---	---	---	---	---	---	0.8
	Odonata	Calopterygidae	*Calopteryx*	T	---	0.8	1.8	0.8	1.7	---	0.8
	Megaloptera	Corydalidae	*Nigronia*	I	3.2	---	---	---	0.9	---	2.4
	Plecoptera	Leuctridae	*Leuctra*	I	---	---	---	---	0.9	---	---
		Nemouridae	*Amphinemura*	I	1.1	---	---	---	---	---	---
	Trichoptera	Hydropsychidae	*Cheumatopsyche*	T	17.2	1.7	16.4	---	6.8	3.3	---
			Diplectrona	I	1.1	---	---	---	---	2.2	2.4
			Hydropsyche	T	10.8	---	12.7	0.8	2.6	2.2	0.8
		Philopotamidae	*Dolophilodes*	I	1.7	2.5	---	1.7	---	---	---
			Chimarra	M	---	---	14.5	---	44.4	15.5	3.2
Mollusca	Basommatophora	Physidae	*Physa*	T	---	---	---	6.7	0.9	30	1.6
Nemertea	Hoplonemertea	Tetrastemmatidae	*Prostoma*	T	0.9	---	---	---	---	---	---

Tolerance values are represented as I, M, or T. Intolerant taxa with tolerance values from 0 to 3 are represented by I. Moderately tolerant taxa with tolerance values from 3.1 to 6.9 are represented by M. Tolerant genera with tolerance values from 7 to 10 are represented by T.

* Taxa not identified to genus.

ATKI-101-X

ATKI-101-X in spring 2018

Coordinates

Latitude	*Longitude*
39.48219	76.34022

Land Use

Catchment	393 Acres	
Land Cover Type	% of Catchment *2001 NLCD*	% of Catchment *2011 NLCD*
Forest	34.7	23.7
Agriculture	19.0	5.0
Urban	46.1	67.8
Other	0.3	3.5

Physical Habitat

Physical habitat parameters are scored on a 0 (poor) to 20 (optimal) scale. Score ranges are: 0-5 (poor), 6-10 (marginal), 11-15 (sub-optimal) and 16-20 (optimal).

Parameter	*2009*	*2010*	*2011*	*2012*	*2013*	*2014*	*2015*	*2016*	*2017*	*2018*
Instream habitat (0-20)	12	13	17	8	15	16	9	16	8	14
Epifaunal substrate (0-20)	15	13	18	8	14	14	11	16	12	13
Velocity/Depth Diversity (0-20)	9	9	15	8	9	11	12	14	11	15
Pool Quality (0-20)	8	8	15	7	7	11	11	13	12	12
Riffle Quality (0-20)	14	9	19	12	12	13	11	15	12	14
Shading (%)	80	85	90	80	70	80	85	90	47	60
Embeddedness (%)	40	40	5	80	25	30	20	30	41	20
Discharge (cfs)	0.85	0.98	0.67	0.54	0.42	0.69	0.25	0.28	0.25	0.75
Bank Erosion (m^2)*	98.1	88.4	60.2	124.0	175.6	125.2	97.2	180.0	3.2	1.5

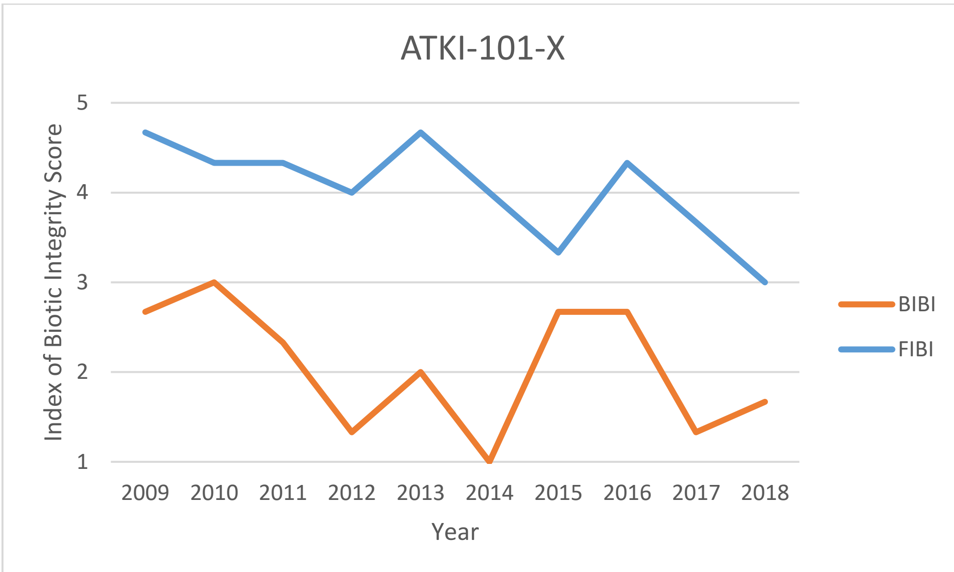
* = Total area of eroded stream banks (sum of left and right banks)

Biology

Indexes of Biotic Integrity.

Metric	*2009*	*2010*	*2011*	*2012*	*2013*	*2014*	*2015*	*2016*	*2017*	*2018*
BIBI	2.67	3.00	2.33	1.33	2.00	1.00	2.67	2.67	1.33	1.67
FIBI	4.67	4.33	4.33	4.00	4.67	4.00	3.33	4.33	3.67	3.00

IBI scores less than 2 are rated very poor, 2 to 2.9 are rated poor, 3 to 3.9 are rated fair, and 4 to 5 are rated good.



Fish species collected and their annual abundance.

Species	*Tolerance*	*2009*	*2010*	*2011*	*2012*	*2013*	*2014*	*2015*	*2016*	*2017*	*2018*
Banded Killifish	NA*	0	0	0	0	0	0	0	0	0	1
Blacknose dace	T	87	122	46	33	67	71	85	97	76	32
Blue ridge sculpin	I	342	217	94	58	169	113	55	195	96	80
Bluegill	T	0	0	0	3	0	0	0	0	0	18
Bluntnose Minnow	T	0	70	28	3	1	16	77	28	93	320
Brown Bullhead	T	0	4	0	0	0	0	0	0	0	0
Common shiner	I	3	3	1	0	1	0	5	10	9	13
Creek chub	T	119	114	89	84	69	44	72	55	79	37
Cutlip Minnow	T	0	0	1	0	0	0	0	0	0	0
Eastern mosquitofish	M	2	198	11	4	2	0	1	26	2	0
Fallfish	I	0	38	10	1	0	0	18	5	6	0
Fathead Minnow	M	0	0	0	0	0	0	0	1	2	0
Largemouth bass	T	0	0	0	0	0	0	0	3	0	0

Species	Tolerance	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Longnose dace	M	3	4	4	2	4	3	6	2	2	0
Pumpkinseed	T	0	0	0	0	0	0	0	2	11	3
Redbreast Sunfish	I	0	0	3	2	0	1	1	0	9	17
Rosyside dace	M	7	4	7	6	4	5	2	14	7	3
Satinfin shiner	I	0	0	0	0	0	0	0	2	0	0
Tessellated darter	T	1	1	0	0	0	0	19	14	0	0
White Sucker	T	0	9	6	2	5	0	48	16	32	11

Tolerance values are represented as I, M, or T. Intolerant species are represented by I, moderately tolerant species are represented by M, and tolerant species are represented by T.
*Insufficient data to determine tolerance.

Crayfish species collected and their annual abundance.

Species	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Common crayfish *(Cambarus bartonii bartonii)*	2	1	0	1	0	0	0	0	0	0
Virile crayfish *(Orconecetes virilis)*	64	22	28	66	145	57	31	22	95	20

Herpetofauna (P) presence or (A) absence.

Order (Common)	Species	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Anura (Frogs and Toads)	*American bullfrog*	P	A	A	A	A	A	A	A	P	A
	Eastern American toad	P	P	A	A	A	P	P	P	P	P
	Fowler's toad	A	P	P	P	A	A	A	A	A	A
	Northern green frog	P	P	P	P	P	P	P	P	P	A
	Northern spring peeper	A	A	A	P	P	A	A	A	A	A
	Pickerel frog	P	P	A	P	P	A	P	P	P	P
Caudata (Salamanders and Newts)	*Eastern red-backed salamander*	A	A	P	A	A	A	A	A	A	A
	Northern dusky salamander	P	A	A	P	A	A	A	A	A	A
	Northern two-lined-salamander	P	P	A	P	P	P	P	P	P	P
Squamata (Snakes and Lizards)	*Northern watersnake*	P	A	A	A	A	A	A	A	P	A
	Queen snake	A	A	A	A	A	A	P	A	A	A
Testudines (Turtles)	*Eastern snapping turtle*	A	P	A	A	A	A	A	A	A	A
	Red-eared slider	A	A	A	A	A	A	A	A	P	A

Benthic macroinvertebrates collected and their annual relative abundance. (genera (RA)) = (number of genera (percent relative abundance)).

Phylum	*Order*	*Family*	*Genus*	*Tolerance*	*2009 RA*	*2010 RA*	*2011 RA*	*2012 RA*	*2013 RA*	*2014 RA*	*2015 RA*	*2016 RA*	*2017 RA*	*2018 RA*
Annelida	*Haplotaxida*	*Naididae*	*n/a*	*T*	---	*5.8	*17.7	---	---	---	*0.8	---	*0.9	---
	Lumbriculida	*Lumbriculidae*	*n/a*	*M*	---	---	---	---	---	---	---	*0.9	*0.9	*0.9
Arthropoda	*Amphipoda*	*Crangonyctidae*	*Crangonyx*	*M*	---	---	---	---	---	---	---	---	---	0.9
	Coleoptera	*Elmidae*	*Oulimnius*	*I*	4.8	0.8	0.9	---	---	---	0.8	7.7	---	0.9
			Stenelmis	*T*	---	---	1.8	---	0.9	0.9	0.8	---	---	---
		Dryopidae	*Helichus*	*M*	---	---	---	---	0.9	---	---	---	---	---
		Psephenidae	*Psephenus*	*M*	2.9	---	0.9	0.9	---	---	---	---	---	---
	Diptera	*Chironomidae*	*n/a*	*M*	*1.0	---	---	---	---	---	---	---	---	---
			Ablabesmyia	*T*	1	---	---	---	---	---	---	---	---	---
			Brillia	*T*	---	---	---	0.9	---	1.7	---	0.9	3.4	---
			Cardiocladius	*T*	---	---	---	0.9	---	---	---	---	---	---
			Chaetocladius	*T*	---	---	---	6.9	0.9	---	1.6	0.9	1.7	---
			Chironomini	*M*	---	---	---	---	---	---	---	4.3	---	---
			Chironomus	*M*	---	*0.8	---	---	---	---	---	*0.9	*0.9	---
			Corynoneura	*M*	---	2.5	---	---	---	---	---	---	---	1.8
			Cricotopus	*T*	---	---	---	---	1.8	---	---	---	---	8
			Cryptochironomus	*T*	---	0.8	---	---	---	---	---	---	---	---
			Diamesa	*T*	1	0.8	2.7	---	---	---	3.2	4.3	6.9	4.5
			Diamesinae	*T*	---	---	---	---	*2.6	---	---	*0.9	---	---
			Dicrotendipes	*T*	---	---	---	---	---	---	0.8	---	---	---
			Eukiefferiella	*M*	---	1.7	---	19.8	---	---	---	---	---	3.6

Phylum	Order	Family	Genus	Tolerance	2009 RA	2010 RA	2011 RA	2012 RA	2013 RA	2014 RA	2015 RA	2016 RA	2017 RA	2018 RA
Arthropoda	*Diptera*	*Chironomidae*	*Hydrobaenus*	*T*	---	0.8	---	---	1.8	---	---	---	---	---
			Limnophyes	*T*	---	0.8	---	---	---	---	---	---	---	---
			Mesocricotopus	*M*	1	---	---	---	---	---	---	---	---	---
			Micropsectra	*I*	6.7	3.3	---	2.6	---	---	---	---	3.4	---
			Nanocladius	*T*	---	---	---	---	0.9	---	---	---	---	---
			Orthocladiinae	*T*	---	*3.3	*5.3	*7.8	---	*6.1	*1.6	---	---	4.5
			Orthocladius	*T*	19	28.1	38.1	37.9	9.6	18.3	20	17.2	22.4	4.5
			Parametriocnemus	*M*	---	0.8	0.9	---	3.5	0.9	---	---	37.9	10.7
			Polypedilum	*M*	1.9	0.8	1.8	---	0.9	0.9	11.2	17.2	0.9	18.8
			Potthastia	*I*	---	---	---	---	---	---	---	---	3.4	---
			Rheocricotopus	*T*	---	---	---	---	---	---	---	---	---	7.1
			Rheotanytarsus	*T*	---	---	---	---	1.8	3.5	---	---	---	3.6
			Smittia	*M*	1	---	---	---	---	---	1.6	---	---	---
			Sublettea	*T*	---	---	---	---	---	---	0.8	---	---	---
			Sympotthastia	*T*	---	---	---	---	19.3	58.3	---	---	0.9	---
			Tanytarsini	*M*	---	---	---	---	---	---	*2.4	---	---	---
			Tanytarsus	*M*	---	---	---	---	2.6	---	1.6	4.3	1.7	---
			Tanypodinae	*T*	*1.0	*1.7	---	---	---	---	---	---	---	---
			Thienemanniella	*M*	---	3.3	0.9	---	---	---	---	---	1.7	---
			Thienemannimyia Group	*T*	---	---	---	---	---	---	---	*1.7	*0.9	1.8
			Tvetenia	*M*	---	4.1	---	4.3	2.6	0.9	---	0.9	8.6	6.3
			Zavrelimyia	*M*	---	0.8	---	---	---	---	---	---	0.9	---

Phylum	Order	Family	Genus	Tolerance	2009 RA	2010 RA	2011 RA	2012 RA	2013 RA	2014 RA	2015 RA	2016 RA	2017 RA	2018 RA
Arthropoda	*Diptera*	*Empididae*	*n/a*	*T*	**1.9*	**1.7*	---	**3.4*	---	---	---	---	**0.9*	---
			Clinocera	*T*	---	---	*15.9*	---	---	---	---	---	---	---
		Simuliidae	*Prosimulium*	*I*	*1*	---	---	---	---	---	---	*0.9*	---	---
			Simulium	*M*	*1*	*4.1*	---	*3.4*	---	---	---	*4.3*	*0.9*	---
		Tipulidae	*Antocha*	*T*	*6.7*	*0.8*	*0.9*	---	*2.6*	*0.9*	*0.8*	---	---	---
			Tipula	*M*	*2.9*	---	*0.9*	*1.7*	*4.4*	*0.9*	*0.8*	---	---	---
	Ephemeroptera	*Baetidae*	*Acentrella*	*M*	*3.8*	*2.5*	---	*4.3*	---	---	*8*	*6*	*0.9*	---
			Baetis	*M*	---	*2.5*	---	---	---	---	---	---	---	---
	Plecoptera	*Nemouridae*	*Amphinemura*	*I*	---	---	*0.9*	---	---	---	---	*2.6*	---	---
	Trichoptera	*Glossosomatidae*	*Glossosoma*	*I*	---	---	*0.9*	---	---	*1.7*	*21.6*	---	---	---
		Hydropsychidae	*n/a*	*T*	**1.0*	---	---	---	---	---	---	**2.6*	---	---
			Cheumatopsyche	*T*	*10.5*	---	*6.2*	---	*24.6*	*3.5*	*18.4*	*6.9*	---	*8.9*
			Diplectrona	*I*	*1*	---	---	*0.9*	---	---	---	*1.7*	---	
		Hydropsychidae	*Hydropsyche*	*T*	*10.5*	*2.5*	*1.8*	---	*7*	*0.9*	*1.6*	*13.8*	---	*5.4*
		Philopotamidae	*Chimarra*	*M*	*13.3*	*0.8*	*1.8*	---	*11.4*	*0.9*	*0.8*	*1.7*	---	*8*
			Dolophilodes	*I*	*4.8*	*24*	---	*0.9*	---	---	---	---	---	---
Platyhelminthes	*Tricladida*	*Dugesiidae*	*Girardia*	*I*	*1*	---	---	*2.6*	---	---	*0.8*	---	---	---

Tolerance values are represented as I, M, or T. Intolerant taxa with tolerance values from 0 to 3 are represented by I. Moderately tolerant taxa with tolerance values from 3.1 to 6.9 are represented by M. Tolerant genera with tolerance values from 7 to 10 are represented by T.

* Taxa not identified to genus.

ATKI-102-X

ATKI-102-X in spring 2018

Coordinates

Latitude	*Longitude*
39.48827	76.33401

Land Use

Catchment	146 Acres	
Land Cover Type	% of Catchment *2001 NLCD*	% of Catchment *2011 NLCD*
Forest	15.7	13.1
Agriculture	18.6	0
Urban	65.7	82.3
Other	0	4.6

Physical Habitat

Physical habitat parameters are scored on a 0 (poor) to 20 (optimal) scale. Score ranges are: 0-5 (poor), 6-10 (marginal), 11-15 (sub-optimal) and 16-20 (optimal)

Parameter	*2009*	*2010*	*2011*	*2012*	*2013*	*2014*	*2015*	*2016*	*2017*	*2018*
Instream habitat (0-20)	12	10	16	10	13	12	12	8	10	14
Epifaunal substrate (0-20)	11	13	17	8	13	13	13	9	14	16
Velocity/Depth Diversity (0-20)	11	11	14	12	11	9	11	11	11	13
Pool Quality (0-20)	11	11	14	13	11	7	12	11	11	14
Riffle Quality (0-20)	9	8	10	11	11	12	14	6	8	16
Shading (%)	75	70	80	75	55	60	80	40	15	30
Embeddedness (%)	40	40	5	55	40	35	40	20	45	20
Discharge (cfs)	0.19	0.16	0.05	0.25	0.06	0.52	0.44	0.09	0.02	0.37
Bank Erosion (m^2)*	66.3	81.5	37.8	70.0	44.2	82.6	86.9	0.8	0.5	1

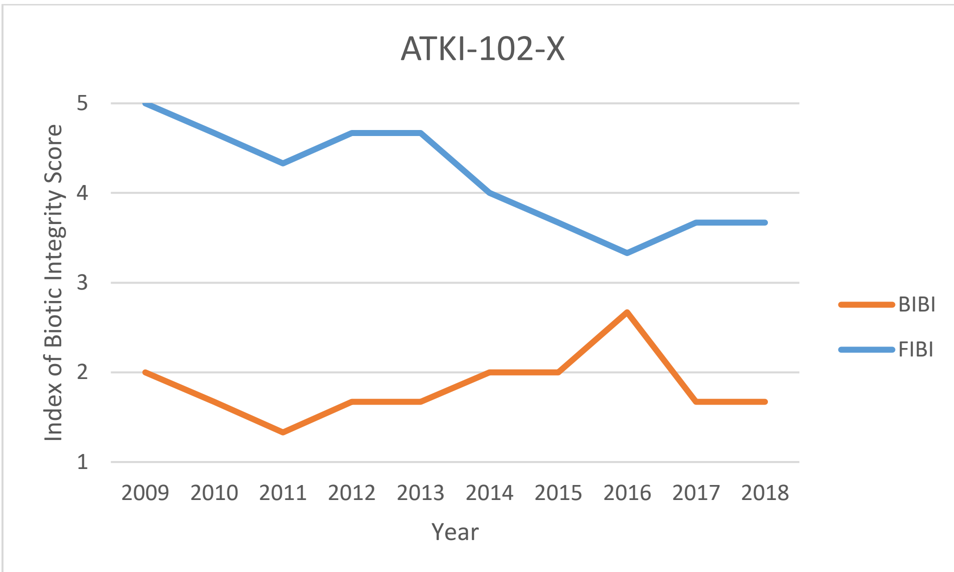
* = Total area of eroded stream banks (sum of left and right banks)

Biology

Indexes of Biotic Integrity.

Metric	*2009*	*2010*	*2011*	*2012*	*2013*	*2014*	*2015*	*2016*	*2017*	*2018*
BIBI	2.00	1.67	1.33	1.67	1.67	2.00	2.00	2.67	1.67	1.67
FIBI	5.00	4.67	4.33	4.67	4.67	4.00	3.67	3.33	3.67	3.67

IBI scores less than 2 are rated very poor, 2 to 2.9 are rated poor, 3 to 3.9 are rated fair, and 4 to 5 are rated good.



Fish species collected and their annual abundance.

Species	*Tolerance*	*2009*	*2010*	*2011*	*2012*	*2013*	*2014*	*2015*	*2016*	*2017*	*2018*
Blacknose dace	T	111	144	129	107	130	277	136	430	383	150
Blue ridge sculpin	I	320	199	142	157	163	159	80	45	46	45
Creek chub	T	144	139	112	109	165	103	101	147	160	109

Tolerance values are represented as I, M, or T. Intolerant species are represented by I, moderately tolerant species are represented by M, and tolerant species are represented by T.

Crayfish species collected and their annual abundance.

Species	*2009*	*2010*	*2011*	*2012*	*2013*	*2014*	*2015*	*2016*	*2017*	*2018*
Common crayfish *(Cambarus bartonii bartonii)*	1	4	0	0	0	0	0	0	0	0
Southern White River Crawfish (Procambarus zonangulus)	0	0	0	0	0	0	0	0	0	1
Virile crayfish *(Orconecetes virilis)*	2	6	5	16	10	15	7	3	18	21
Unknown Procambarus *(Procambarus sp.)*	1	0	0	2	0	0	0	0	0	0

Herpetofauna (P) presence or (A) absence.

Order (Common)	*Species*	*2009*	*2010*	*2011*	*2012*	*2013*	*2014*	*2015*	*2016*	*2017*	*2018*
Anura (Frogs and Toads)	*American Bullfrog*	A	A	A	A	A	A	A	A	A	P
	Cope's gray treefrog	A	A	A	A	P	A	A	A	P	A
	Eastern American toad	A	P	A	A	A	A	A	A	A	A
	Gray treefrog	A	A	A	A	A	A	P	A	A	A
	Northern green frog	P	P	P	A	P	P	P	P	P	P
	Northern spring peeper	A	A	A	A	P	A	A	A	A	A
	Pickerel frog	P	P	A	P	A	A	A	P	P	A
Caudata (Salamanders and Newts)	*Northern dusky salamander*	A	P	A	P	A	A	A	A	A	A
	Northern red salamander	P	P	A	P	A	A	A	A	A	A
	Northern two-lined salamander	P	P	P	P	P	P	P	P	P	A
Testudines (Turtles)	*Eastern painted turtle*	A	A	A	A	A	P	A	A	A	A
	Eastern snapping turtle	A	A	A	A	A	P	A	A	A	A

Benthic macroinvertebrates collected and their annual relative abundance. (genera (RA)) = (number of genera (percent relative abundance)).

Phylum	*Order*	*Family*	*Genus*	*Tolerance*	*2009 RA*	*2010 RA*	*2011 RA*	*2012 RA*	*2013 RA*	*2014 RA*	*2015 RA*	*2016 RA*	*2017 RA*	*2018 RA*
Annelida	*Haplotaxida*	*Naididae*	*n/a*	*T*	---	**1.8*	---	---	**7.3*	---	---	**5.6*	---	---
		Tubificdae	*n/a*	*T*	---	---	**0.8*	---	**0.9*	**0.9*	**0.8*	---	---	---
	Lumbriculida	*Lumbriculidae*	*n/a*	*M*	**0.9*	---	---	---	---	---	*3.1*	---	---	---
Arthropoda	*Coleoptera*	*Elmidae*	*Optioservus*	*M*	---	*0.6*	---	---	---	---	---	---	*0.8*	---
			Oulimnius	*I*	*4.5*	---	---	---	*0.9*	*0.9*	---	---	---	---
			Stenelmis	*T*	*12.7*	---	*4*	*1*	*2.7*	---	*5.5*	*0.8*	*0.8*	---
		Psephenidae	*Psephenus*	*M*	*0.9*	---	---	---	---	---	---	---	---	---
	Collembola	*Isotomidae*	*Isotomurus*	*M*	---	---	---	---	---	*0.9*	---	---	---	---
	Diptera	*Ceratopogonidae*	*n/a*	*M*	---	---	**1.6*	---	---	---	---	---	---	**0.8*
		Chironomidae	*Chaetocladius*	*T*	*27.3*	---	*4*	*2.9*	---	---	---	*1.6*	---	---
			Chironomini	*M*	---	---	---	---	---	---	---	---	*0.8*	---
			Chironomus	*M*	---	---	---	---	---	---	---	*21.6*	---	---
			Cryptochironomus	*T*	---	---	---	---	---	---	*0.8*	---	---	---
			Corynoneura	*M*	---	*0.6*	---	---	---	---	---	*0.8*	---	---
			Cricotopus	*T*	---	*1.2*	---	---	---	---	---	---	---	*40.9*
			Diamesa	*T*	---	---	*9.6*	---	---	---	*16.4*	*2.4*	*0.8*	---
			Diamesinae	*T*	---	---	---	---	---	---	---	*2.4*	---	---
			Dicrotendipes	*T*	---	---	*0.8*	*2.9*	---	---	---	---	*0.8*	*1.6*
			Eukiefferiella	*M*	---	*11.2*	---	*1.9*	---	---	---	*0.8*	---	---
			Limnophyes	*T*	---	---	---	*2.9*	---	---	---	---	---	---
			Microtendipes	*M*	---	---	---	---	---	---	---	---	*2.5*	*0.8*
			Micropsectra	*I*	*0.9*	*20.1*	---	---	---	---	---	*4*	---	---

Phylum	Order	Family	Genus	Tolerance	2009 RA	2010 RA	2011 RA	2012 RA	2013 RA	2014 RA	2015 RA	2016 RA	2017 RA	2018 RA
Arthropoda	*Diptera*	*Chironomidae*	*Orthocladiinae*	*T*	*2.7	*4.1	*9.6	*1.9	*0.9	*0.9	---	*7.2	*2.5	4.7
			Orthocladius	*T*	14.5	22.5	56	31.7	50.9	20.9	11.7	48.8	13.4	7.1
			Parametriocnemus	*M*	---	---	---	2.9	---	---	0.8	---	21	---
			Paratanytarsus	*T*	---	---	1.6	1.9	---	---	---	---	---	2.4
			Phaenopsectra	*T*	---	---	---	---	---	---	---	---	---	0.8
			Polypedilum	*M*	2.7	1.2	0.8	15.4	---	1.8	19.5	---	16	7.9
			Potthastia	*I*	---	---	---	3.8	---	---	---	---	---	---
			Rheocricotopus	*M*	---	---	---	---	---	---	---	0.8	---	2.4
			Rheotanytarsus	*T*	2.7	---	---	---	2.7	3.6	1.6	---	3.4	6.3
			Sympotthastia	*T*	---	---	---	---	---	0.9	---	---	---	---
			Tanypodinae	*T*	---	*0.6	---	---	---	---	---	---	*2.5	---
			Tanytarsini	*M*	---	---	---	---	*0.9	---	*2.3	---	*0.8	---
			Tanytarsus	*M*	---	---	---	1	2.7	---	9.4	0.8	4.2	6.3
			Thienemanniella	*M*	---	1.2	---	---	---	---	---	0.8	---	0.8
			Thienemannimyia Group	*T*	*0.9	---	---	---	---	*0.9	---	---	*6.7	*2.4
			Tvetenia	*M*	---	1.8	---	13.5	1.8	3.6	---	1.6	5.9	3.9
			Zavrelimyia	*M*	---	0.6	---	---	---	---	---	---	---	---
		Empididae	*n/a*	*T*	---	*0.6	---	*1.0	---	*0.9	---	---	---	---
			Clinocera	*T*	2.7	---	0.8	---	---	---	---	---	---	---
			Hemerodromia	*T*	---	---	---	1	---	---	---	---	---	---
		Simuliidae	*Simulium*	*M*	---	1.8	---	1	---	---	---	---	---	---
		Tipulidae	*Antocha*	*T*	0.9	---	0.8	---	0.9	2.7	---	---	3.4	2.4

Phylum	Order	Family	Genus	Tolerance	2009 RA	2010 RA	2011 RA	2012 RA	2013 RA	2014 RA	2015 RA	2016 RA	2017 RA	2018 RA
Arthropoda	*Diptera*	*Tipulidae*	*Tipula*	*M*	---	*0.6*	---	---	*1.8*	*0.9*	*2.3*	---	*0.8*	*0.8*
	Ephemeroptera	*Baetidae*	*Baetis*	*M*	---	*3*	---	---	---	---	---	---	---	---
			Acentrella	*M*	---	---	---	*1*	---	---	---	---	---	---
	Odonata	*Coenagrionidae*	*Argia*	*T*	---	---	---	---	---	*0.9*	---	---	---	---
	Trichoptera	*Glossosomatidae*	*Glossosoma*	*I*	---	---	---	---	---	---	*10.2*	---	---	---
		Hydropsychidae	*n/a*	*T*	---	---	---	---	---	**1.8*	---	---	---	---
		Hydropsychidae	*Cheumatopsyche*	*T*	*4.5*	---	---	*5.8*	*12.7*	*13.6*	*7*	---	*8.4*	*1.6*
			Diplectrona	*I*	*4.5*	---	*0.8*	---	---	*0.9*	---	---	---	---
			Hydropsyche	*T*	*11.8*	*1.8*	*3.2*	*1*	*4.5*	*9.1*	*5.5*	---	*1.7*	*2.4*
		Philopotamidae	*n/a*	*I*	---	---	---	**1.0*	---	---	---	---	---	---
			Chimarra	*M*	*4.5*	*1.2*	*4.8*	*4.8*	*7.3*	*30.9*	*1.6*	---	*2.5*	*3.1*
		Philopotomidae	*Dolophilodes*	*I*	---	*12.4*	---	---	---	---	---	---	---	---
Arthropoda	*Trichoptera*	*Polycentropodidae*	*Nyctiophylax*	*I*	---	---	---	---	*0.9*	---	---	---	---	---
Mollusca	*Basommatophora*	*Physidae*	*Physa*	*T*	---	---	*0.8*	---	---	*0.9*	*0.8*	---	---	---
	Veneroida	*Pisidiidae*	*Musculium*	*M*	---	---	---	---	---	*0.9*	---	---	---	---
Nematoda	*n/a*	*n/a*	*n/a*	*M*	---	---	---	---	---	---	---	---	---	**0.8*
Nematomorpha	*Gordioidea*	*Gordiidae*	*n/a*	*M*	---	---	---	---	---	---	**0.8*	---	---	---
Platyhelminthes	*Tricladida*	*Dugesiidae*	*Girardia*	*T*	---	---	---	---	---	*0.9*	---	---	---	---

Tolerance values are represented as I, M, or T. Intolerant taxa with tolerance values from 0 to 3 are represented by I. Moderately tolerant taxa with tolerance values from 3.1 to 6.9 are represented by M. Tolerant genera with tolerance values from 7 to 10 are represented by T.

* Taxa not identified to genus.

ATKI-105-X

ATKI-105-X in spring 2015

Coordinates

Latitude	*Longitude*
39.49187	76.33392

Land Use

Catchment	107 Acres	
Land Cover Type	% of Catchment *2001 NLCD*	% of Catchment *2011 NLCD*
Forest	17.4	16.1
Agriculture	19.9	0
Urban	62.7	77.7
Other	0	6.3

Physical Habitat

Physical habitat parameters are scored on a 0 (poor) to 20 (optimal) scale. Score ranges are: 0-5 (poor), 6-10 (marginal), 11-15 (sub-optimal) and 16-20 (optimal).

Parameter	*2009*	*2010*	*2011*	*2012*	*2013*	*2014*	*2015*
Instream habitat (0-20)	12	12	14	8	8	12	8
Epifaunal substrate (0-20)	10	9	12	6	7	13	10
Velocity/Depth Diversity (0-20)	12	11	8	8	7	7	11
Pool Quality (0-20)	12	12	9	6	7	7	12
Riffle Quality (0-20)	11	8	7	8	9	11	8
Shading (%)	40	25	55	40	40	30	60
Embeddedness (%)	60	40	20	70	65	20	64
Discharge (cfs)	0.11	0.05	0.05	1.98	0.12	0.11	0.19
Bank Erosion (m^2)*	130.0	95.2	6.5	111.3	159.9	13.6	32.8

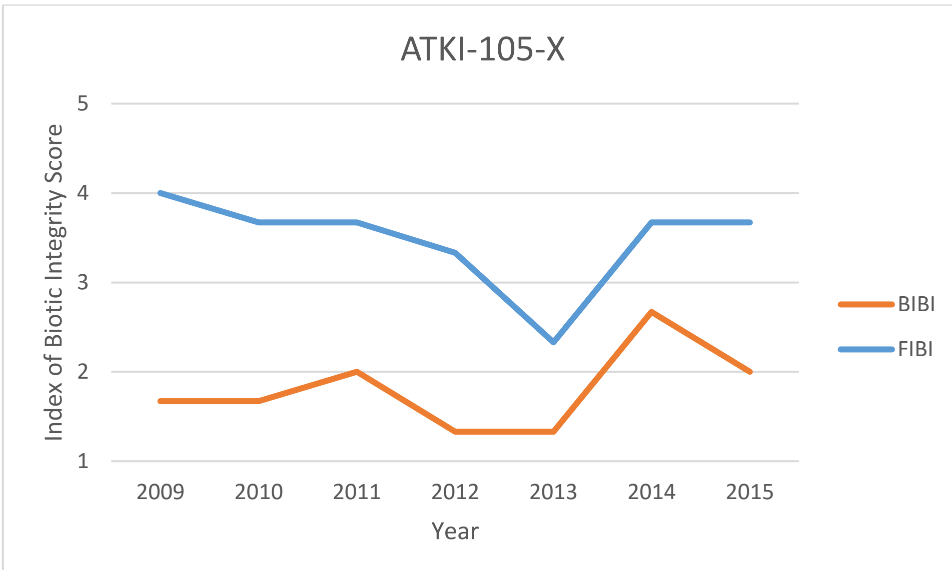
* = Total area of eroded stream banks (sum of left and right banks)

Biology

Indexes of Biotic Integrity.

Metric	*2009*	*2010*	*2011*	*2012*	*2013*	*2014*	*2015*
BIBI	1.67	1.67	2.00	1.33	1.33	2.67	2.00
FIBI	4.00	3.67	3.67	3.33	2.33	3.67	3.67

IBI scores less than 2 are rated very poor, 2 to 2.9 are rated poor, 3 to 3.9 are rated fair, and 4 to 5 are rated good.



Fish species collected and their annual abundance.

Species	*Tolerance*	*2009*	*2010*	*2011*	*2012*	*2013*	*2014*	*2015*
Blacknose dace	T	132	192	29	20	125	71	166
Blue ridge sculpin	I	7	2	2	5	0	6	3
Creek chub	T	317	182	121	116	92	67	152

Tolerance values are represented as I, M, or T. Intolerant species are represented by I, moderately tolerant species are represented by M, and tolerant species are represented by T.

Crayfish species collected and their annual abundance.

Species	*2009*	*2010*	*2011*	*2012*	*2013*	*2014*	*2015*
Virile crayfish *(Orconecetes virilis)*	4	0	0	0	4	6	10
Unknown Procambarus *(Procambarus sp.)*	5	2	11	21	1	8	0

Herpetofauna (P) presence or (A) absence.

Order (Common)	*Species*	*2009*	*2010*	*2011*	*2012*	*2013*	*2014*	*2015*
Anura (Frogs and Toads)	*American bullfrog*	A	A	A	A	A	P	A
	Cope's gray treefrog	A	A	A	P	A	A	A
	Northern green frog	P	P	P	P	P	P	P
	Pickerel frog	P	A	A	A	A	A	P
Caudata (Salamanders and Newts)	*Northern two-lined salamander*	P	P	A	P	P	P	A
Testudines (Turtles)	*Eastern snapping turtle*	A	A	P	A	A	A	A

Benthic macroinvertebrates collected and their annual relative abundance. (genera (RA)) = (number of genera (percent relative abundance)).

Phylum	*Order*	*Family*	*Genus*	*Tolerance*	*2009 RA*	*2010 RA*	*2011 RA*	*2012 RA*	*2013 RA*	*2014 RA*	*2015 RA*
Annelida	Haplotaxida	Enchytraeidae	*n/a*	T	---	---	*0.8	---	---	---	---
			Limnodrilus	T	1	---	---	---	---	---	---
		Naididae	*n/a*	T	---	---	*0.8	*0.8	*67.8	---	---
	Lumbriculida	Lumbriculidae	*n/a*	M	---	---	*1.6	*4.7	*0.8	---	---
	Tubificida	Tubificidae	*n/a*	T	---	*4.5	*6.5	*7.0	*0.8	*1.7	*8.8
Arthropoda	Coleoptera	Elmidae	*Dubiraphia*	M	---	---	---	---	---	---	0.9
			Stenelmis	T	11.3	1.8	16.1	---	0.8	5.2	13.2
		Psephenidae	*Psephenus*	M	---	---	---	---	---	---	0.9
	Diptera	Chironomidae	*Brillia*	T	---	0.9	---	---	---	---	---
			Dicrotendipes	T	4.1	---	0.8	---	0.8	0.9	2.6
			Chironomini	M	---	*0.9	*0.8	---	---	---	---
			Chironomus	M	---	2.7	---	---	---	---	---
			Corynoneura	M	---	---	---	---	0.8	---	---
			Cricotopus	T	---	---	---	---	7.6	0.9	---
			Cryptochironomus	T	---	---	---	---	---	---	0.9
			Diamesa	T	---	---	---	---	---	0.9	---
			Endochironomus	M	1	---	---	---	---	---	---
			Eukiefferiella	M	---	17	---	3.9	---	---	---
			Hydrobaenus	T	---	---	4	---	---	---	---
			Limnophyes	T	---	1.8	---	0.8	0.8	---	---
			Micropsectra	I	---	15.2	---	---	---	---	7
			Orthocladiinae	T	*4.1	*2.7	*2.4	*6.2	*1.7	---	*0.9
			Orthocladius	T	38.1	33.9	37.1	48.1	10.2	0.9	17.5
			Paratanytarsus	T	---	0.9	0.8	---	2.5	4.3	---
			Phaenopsectra	T	---	---	0.8	---	---	---	---
			Polypedilum	M	2.1	---	---	13.2	---	---	3.5
			Potthastia	I	---	---	---	0.8	---	---	---
			Prodiamesa	M	---	0.9	---	---	---	---	---

Phylum	*Order*	*Family*	*Genus*	*Tolerance*	*2009 RA*	*2010 RA*	*2011 RA*	*2012 RA*	*2013 RA*	*2014 RA*	*2015 RA*
Arthropoda	Diptera	Chironomidae	*Rheotanytarsus*	T	---	0.9	2.4	---	1.7	---	0.9
			Tanypodinae	T	---	---	*1.6	---	---	---	*0.9
			Tanytarsus	M	---	---	---	---	0.8	---	---
			Thienemannimyia Group	T	*4.1	*0.9	*5.6	---	---	*1.7	*1.8
			Tvetenia	M	---	6.3	---	---	2.5	2.6	1.8
			Zavrelimyia	M	---	0.9	---	---	---	---	---
		Empididae	*n/a*	T	---	---	---	---	---	---	*0.9
			Hemerodromia	T	---	1.8	---	2.3	---	---	1.8
		Simuliidae	*Simulium*	M	---	1.8	---	---	---	0.9	---
		Tipulidae	*Antocha*	T	---	---	---	---	---	---	0.9
			Erioptera	M	1	---	---	---	---	---	---
			Limonia	M	---	---	---	---	---	0.9	---
			Tipula	M	1	---	---	---	---	1.7	---
	Odonata	Aeshnidae	*Boyeria*	M	---	---	---	---	---	---	0.9
		Calopterygidae	*Calopteryx*	T	---	---	2.4	---	---	0.9	---
		Coenagrionidae	*n/a*	T	*1.0	---	---	---	---	---	---
			Argia	T	---	---	---	0.8	---	0.9	---
	Trichoptera	Hydropsychidae	*n/a*	T	---	---	---	*1.6	---	---	---
			Cheumatopsyche	T	6.2	0.9	4	7	---	35.7	15.8
			Hydropsyche	T	24.7	3.6	4.8	1.6	---	14.8	15.8
		Philopotamidae	*Chimarra*	M	---	---	4	1.6	---	24.3	2.6
		Polycentropodidae	*Nyctiophylax*	I	---	---	---	---	---	0.9	---
Mollusca	Basommatophora	Lymnaeidae	*n/a*	M	---	---	*0.8	---	---	---	---
	Veneroida	Pisidiidae	*Musculium*	M	---	---	0.8	---	---	---	---

Tolerance values are represented as I, M, or T. Intolerant taxa with tolerance values from 0 to 3 are represented by I. Moderately tolerant taxa with tolerance values from 3.1 to 6.9 are represented by M. Tolerant genera with tolerance values from 7 to 10 are represented by T.

* Taxa not identified to genus.

ATKI-107-X

ATKI-107-X in spring 2015

*Sampling did not occur in 2013 due to construction

Coordinates

Latitude	Longitude
39.49452	76.33070

Land Use

Catchment	50 Acres	
Land Cover Type	% of Catchment *2001 NLCD*	% of Catchment *2011 NLCD*
Forest	30.4	27.4
Agriculture	8.8	0
Urban	60.8	66.4
Other	0	6.3

Physical Habitat

Physical habitat parameters are scored on a 0 (poor) to 20 (optimal) scale. Score ranges are: 0-5 (poor), 6-10 (marginal), 11-15 (sub-optimal) and 16-20 (optimal).

Parameter	*2009*	*2010*	*2011*	*2012*	*2013*	*2014*	*2015*
Instream habitat (0-20)	3	7	4	5	X	5	10
Epifaunal substrate (0-20)	3	11	10	5	X	7	9
Velocity/Depth Diversity (0-20)	6	10	8	6	X	6	7
Pool Quality (0-20)	6	7	5	8	X	6	6
Riffle Quality (0-20)	6	9	6	9	X	6	12
Shading (%)	25	10	20	5	X	25	30

Parameter	*2009*	*2010*	*2011*	*2012*	*2013*	*2014*	*2015*
Embeddedness (%)	70	10	20	60	X	30	50
Discharge (cfs)	0.04	0.22	0.06	0.05	0.01	0.02	0.22
Bank Erosion (m^2)*	11.7	21.2	0.64	32.7	X	5.6	7.8

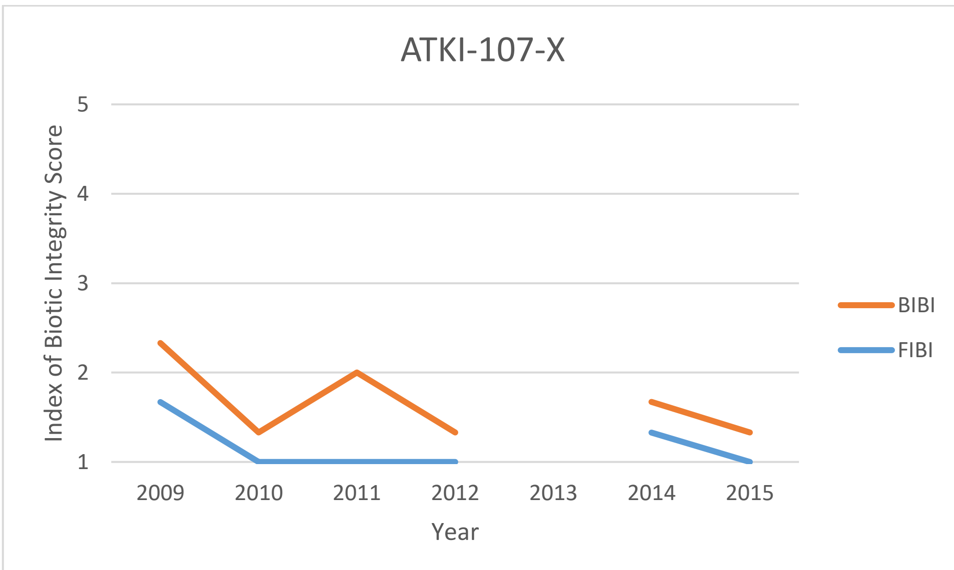
* = Total area of eroded stream banks (sum of left and right banks)

Biology

Indexes of Biotic Integrity.

Metric	*2009*	*2010*	*2011*	*2012*	*2013*	*2014*	*2015*
BIBI	2.33	1.33	2.00	1.33	X	1.67	1.33
FIBI	1.67	1.00	1.00	1.00	X	1.33	1.00

IBI scores less than 2 are rated very poor, 2 to 2.9 are rated poor, 3 to 3.9 are rated fair, and 4 to 5 are rated good.



Fish species collected and their annual abundance.

Species	*Tolerance*	*2009*	*2010*	*2011*	*2012*	*2013*	*2014*	*2015*
Blacknose dace	T	0	0	0	0	X	1	0
Creek chub	T	1	0	0	0	X	1	0

Tolerance values are represented as I, M, or T. Intolerant species are represented by I, moderately tolerant species are represented by M, and tolerant species are represented by T.

Crayfish species collected and their annual abundance.

Species	*2009*	*2010*	*2011*	*2012*	*2013*	*2014*	*2015*
Devil crawfish (Cambarus Diogenes)	*P*	*0*	*0*	*1*	*X*	*0*	*0*
Unknown Cambarus (Cambarus sp.)	*1*	*0*	*0*	*0*	*X*	*0*	*0*
Virile Crayfish (Orconectes virilis)	*0*	*0*	*9*	*0*	*X*	*0*	*0*
Unknown Procambarus (Procambarus sp.)	*5*	*19*	*8*	*32*	*X*	*3*	*2*

Herpetofauna (P) presence or (A) absence.

Order (Common)	*Species*	*2009*	*2010*	*2011*	*2012*	*2013*	*2014*	*2015*
Anura (Frogs and Toads)	American bullfrog	P	A	A	A	A	A	A
	Northern green frog	A	P	A	A	A	P	P
	Pickerel frog	A	A	A	P	P	P	A
Caudata (Salamanders and Newts)	Northern two-lined salamander	P	P	A	P	P	P	A
Squamata (Snakes and Lizards)	Queen snake	A	A	A	P	A	A	A

Benthic macroinvertebrates collected and their annual relative abundance. (genera (RA)) = (number of genera (percent relative abundance)).

Phylum	*Order*	*Family*	*Genus*	*Tolerance*	*2009 RA*	*2010 RA*	*2011 RA*	*2012 RA*	*2013 RA*	*2014 RA*	*2015 RA*
Annelida	Haplotaxida	Enchytraeidae	*n/a*	T	---	*0.8	---	---	---	---	---
		Naididae	*n/a*	T	---	---	---	*6.0	---	---	---
	Tubificida	Tubificidae	*n/a*	T	*2.2	*0.8	---	*1.7	---	---	---
	Lumbriculida	Lumbriculidae	*n/a*	M	*2.2	*1.6	*5.0	---	---	---	*4.2
Arthropoda	Coleoptera	Elmidae	*Stenelmis*	T	---	---	---	---	---	---	0.8
		Psephenidae	*Psephenus*	M	---	---	---	---	---	---	1.7
	Collembola	Isotomidae	*Isotomurus*	M	---	---	0.8	---	---	1.7	---
	Decapoda	Cambaridae	*Procambarus*	I	---	---	---	---	---	---	0.8
	Diptera	Ceratopogonidae	*n/a*	M	---	---	*0.8	---	---	*0.8	---
		Chironomidae	*Alotanypus*	M	---	---	---	---	---	---	0.8
			Brillia	T	---	---	---	0.9	---	---	---
			Chironomus	M	---	0.8	24.8	---	---	---	---
			Cricotopus	T	4.3	19.5	0.8	13.8	---	5.8	2.5
			Diamesa	T	---	---	0.8	---	---	---	10.8
			Dicrotendipes	T	1.1	---	---	---	---	---	---
			Eukiefferiella	M	---	1.6	---	28.4	---	---	---
			Limnophyes	T	---	---	---	0.9	---	0.8	---
			Micropsectra	I	---	0.8	---	2.6	---	---	---
			Orthocladiinae	T	---	*4.9	*0.8	*1.7	---	*2.5	*2.5

Phylum	*Order*	*Family*	*Genus*	*Tolerance*	*2009 RA*	*2010 RA*	*2011 RA*	*2012 RA*	*2013 RA*	*2014 RA*	*2015 RA*
Arthropoda	Diptera	Chironomidae	*Orthocladius*	T	3.2	57.7	2.5	19	---	9.2	35.8
			Parametriocnemus	M	---	1.6	---	---	---	---	---
			Polypedilum	M	1.1	---	---	0.9	---	---	2.5
			Tanytarsini	M	---	---	---	---	---	---	*0.8
			Thienemannimyia Group	T	*2.2	---	*2.5	---	---	*23.3	*3.3
			Tvetenia	M	---	0.8	---	1.7	---	0.8	---
			Zavrelimyia	M	---	---	0.8	---	---	---	---
		Empididae	*Hemerodromia*	T	1.1	0.8	---	---	---	---	---
		Simuliidae	*Simulium*	M	---	---	---	0.9	---	---	---
		Sciomyzidae	*n/a*	M	---	---	---	*0.9	---	---	---
		Tipulidae	*n/a*	M	*1.1	---	---	---	---	---	---
			Antocha	T	1.1	---	---	---	---	---	---
			Tipula	M	1.1	---	0.8	0.9	---	---	1.7
	Odonata	Coenagrionidae	*Argia*	T	2.2	---	1.7	0.9	---	---	---
	Trichoptera	Hydropsychidae	*n/a*	T	*1.1	---	---	*1.7	---	---	*0.8
		Hydropsychidae	*Cheumatopsyche*	T	28	1.6	16.5	4.3	---	20.8	8.3
			Hydropsyche	T	41	2.4	38.8	0.9	---	4.2	10
		Philopotamidae	*Chimarra*	M	---	0.8	1.7	0.9	---	26.7	10.8
			Dolophilodes	I	---	---	---	4.3	---	---	---
Mollusca	Basommatohora	Ancylidae	*Ferrissia*	T	---	---	---	---	---	1.7	---
		Physidae	*Physa*	T	2.2	---	---	6.9	---	3.9	1.7

Tolerance values are represented as I, M, or T. Intolerant taxa with tolerance values from 0 to 3 are represented by I. Moderately tolerant taxa with tolerance values from 3.1 to 6.9 are represented by M. Tolerant genera with tolerance values from 7 to 10 are represented by T.

* Taxa not identified to genus.

LWIN-108-X

LWIN-108-X in spring 2018

Coordinates

Latitude	*Longitude*
39.46891	76.32773

Land Use

Catchment	412 Acres	
Land Cover Type	% of Catchment *2001 NLCD*	% of Catchment *2011 NLCD*
Forest	23.4	23.9
Agriculture	26.1	2.6
Urban	50.5	73.0
Other	0.1	0.5

Physical Habitat

Physical habitat parameters are scored on a 0 (poor) to 20 (optimal) scale. Score ranges are: 0-5 (poor), 6-10 (marginal), 11-15 (sub-optimal) and 16-20 (optimal).

Parameter	*2009*	*2010*	*2011*	*2012*	*2013*	*2014*	*2015*	*2016*	*2017*	*2018*
Instream habitat (0-20)	14	14	17	16	11	15	15	11	10	13
Epifaunal substrate (0-20)	16	15	16	11	12	16	15	11	9	15
Velocity/Depth Diversity (0-20)	9	8	14	15	11	12	12	12	13	12
Pool Quality (0-20)	7	9	14	16	11	11	12	11	13	11
Riffle Quality (0-20)	13	14	15	14	8	15	16	13	13	12
Shading (%)	85	85	65	90	80	75	85	90	80	95
Embeddedness (%)	20	20	10	55	40	20	20	50	60	45
Discharge (cfs)	0.33	0.69	1.97	0.97	0.22	0.62	1.64	0.64	0.33	0.46
Bank Erosion (m^2)*	84.8	110.6	80.2	134.4	158.4	63.0	126.0	185.0	163.8	199.3

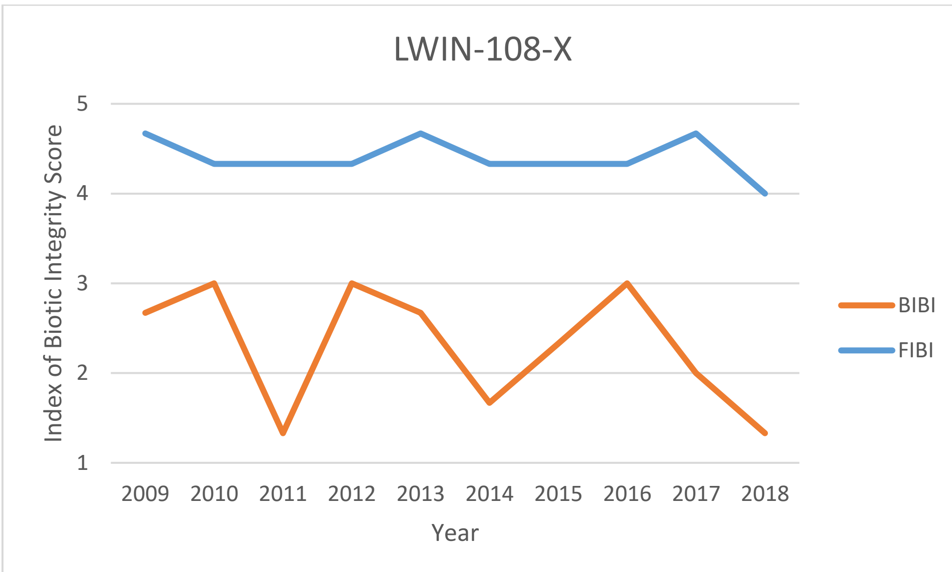
* = Total area of eroded stream banks (sum of left and right banks)

Biology

Indexes of Biotic Integrity.

Metric	*2009*	*2010*	*2011*	*2012*	*2013*	*2014*	*2015*	*2016*	*2017*	*2018*
BIBI	2.67	3.00	1.33	3.00	2.67	1.67	2.33	3.00	2.00	1.33
FIBI	4.67	4.33	4.33	4.33	4.67	4.33	4.33	4.33	4.67	4.00

IBI scores less than 2 are rated very poor, 2 to 2.9 are rated poor,
3 to 3.9 are rated fair, and 4 to 5 are rated good.



Fish species collected and their annual abundance.

Species	*Tolerance*	*2009*	*2010*	*2011*	*2012*	*2013*	*2014*	*2015*	*2016*	*2017*	*2018*
American eel	T	2	5	4	8	4	7	8	10	21	22
Blacknose dace	T	80	149	40	52	101	34	45	108	60	34
Blue ridge sculpin	I	161	274	140	102	148	88	77	114	122	35
Bluntnose Minnow	T	0	4	3	9	2	3	2	8	0	3
Common shiner	I	0	0	0	0	0	0	0	7	3	3
Creek chub	T	68	129	77	55	72	31	36	56	44	25
Eastern mosquitofish	M	0	0	0	0	0	0	0	0	228	0
Fallfish	I	0	5	0	0	0	0	1	1	1	0
Green Sunfish	T	0	0	0	0	0	0	0	0	0	1
Largemouth bass	T	0	0	0	0	0	0	0	2	0	0
Longnose dace	M	2	6	5	8	8	4	8	8	10	4
Margined madtom	I	1	1	1	10	15	7	15	11	5	5

Species	Tolerance	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Pumpkinseed	T	0	0	0	1	0	0	0	0	0	0
Redbreast sunfish	I	0	0	0	1	25	6	1	0	1	2
River chub	I	0	0	0	1	1	0	0	1	0	0
Rosyside dace	M	28	18	10	28	40	12	36	48	25	19
Smallmouth Bass	M	0	1	0	0	0	0	0	1	0	2
Tessellated darter	T	0	0	0	0	3	0	2	0	0	0
White sucker	T	2	2	2	1	5	3	0	11	1	0

Tolerance values are represented as I, M, or T. Intolerant species are represented by I, moderately tolerant species are represented by M, and tolerant species are represented by T.

Crayfish species collected and their annual abundance.

Species	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Common crayfish (Cambarus bartonii bartonii)	4	5	3	1	6	0	4	1	5	1
Devil crawfish (Cambarus diogenes)	0	0	0	0	0	1	0	0	0	0
Spiny Cheek crayfish (Orconecetes limosus)	0	8	9	1	11	0	5	0	20	0
Virile crayfish (Orconecetes virilis)	2	0	1	13	0	3	3	3	0	0

Herpetofauna (P) presence or (A) absence.

Order (Common)	Species	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Anura (Frogs and Toads)	*Eastern American toad*	P	A	A	A	A	P	A	A	A	A
	Cope's gray treefrog	A	A	A	A	A	A	A	A	P	A
	Northern green frog	A	P	A	A	P	A	A	P	P	A
	Pickerel frog	A	A	A	A	P	A	A	A	A	A
	Wood frog	P	A	A	A	A	A	P	A	P	A
Caudata (Salamanders and Newts)	*Eastern red-backed salamander*	A	A	P	A	A	A	A	A	A	A
	Northern dusky salamander	A	A	A	A	A	A	P	A	A	A
	Northern red salamander	A	A	A	A	A	P	A	A	A	A
	Northern two-lined salamander	P	P	A	P	P	P	P	P	P	P
Squamata (Snakes and Lizards)	*Northern ring-necked snake*	P	A	A	A	A	A	A	A	A	A
	Northern watersnake	A	A	A	P	A	A	A	A	A	A
Testudines (Turtles)	*Eastern box turtle*	P	A	A	A	P	A	A	A	A	A

Benthic macroinvertebrates collected and their annual relative abundance. (genera (RA)) = (number of genera (percent relative abundance)).

Phylum	*Order*	*Family*	*Genus*	*Tolerance*	*2009 RA*	*2010 RA*	*2011 RA*	*2012 RA*	*2013 RA*	*2014 RA*	*2015 RA*	*2016 RA*	*2017 RA*	*2018 RA*
Annelida	*Haplotaxida*	*Naididae*	*n/a*	*T*	---	**0.9*	**3.2*	---	**8.8*	---	---	---	**3.3*	---
	Lumbriculida	*Lumbriculidae*	*n/a*	*M*	**4.8*	---	---	---	**1.0*	---	---	---	**0.8*	**0.8*
Arthropoda	*Coleoptera*	*Dytiscidae*	*Neoporous*	*M*	---	---	---	---	---	---	---	*0.8*	---	---
		Elmidae	*Ancyronyx*	*T*	---	---	---	---	---	---	---	*0.8*	---	---
		Ptilodactylidae	*Anchytarsus*	*M*	---	---	---	---	---	---	---	*0.8*	---	---
	Diptera	*Chironomidae*	*Ablabesmyia*	*T*	---	---	---	*0.9*	*1*	---	*0.9*	*0.8*	---	---
			Brillia	*T*	---	---	*2.4*	*0.9*	*1*	*1.7*	---	*2.5*	*0.8*	---
			Chaetocladius	*T*	*9.6*	---	---	---	---	---	---	---	---	*3.4*
			Chironominae	*M*	---	---	---	---	---	**0.9*	---	---	---	---
			Chironomini	*M*	---	---	---	---	---	---	**1.9*	**1.7*	**0.8*	---
			Corynoneura	*M*	---	---	*1.6*	*0.9*	---	---	---	---	*0.8*	---
			Cricotopus	*T*	*1.9*	---	---	---	---	---	---	---	---	*1.7*
			Diamesa	*T*	---	*0.9*	---	---	*3.9*	*5.2*	*3.7*	*0.8*	*0.8*	*0.8*
			Diamesinae	*T*	---	---	---	---	---	---	---	*0.8*	---	*3.4*
			Eukiefferiella	*M*	---	*0.9*	---	*5.2*	---	*0.9*	---	*0.8*	---	---
			Hydrobaenus	*T*	*6.7*	---	*21.8*	---	*12.7*	*3.5*	---	*3.3*	*0.8*	---
			Limnophyes	*T*	---	---	---	---	---	---	---	---	*0.8*	---
			Microtendipes	*T*	---	---	---	---	---	---	---	---	---	*1.7*
			Micropsectra	*I*	*7.7*	*2.6*	*4*	*1.7*	---	*2.6*	---	---	*0.8*	*0.8*
			Orthocladiinae	*T*	**5.8*	**2.6*	**2.4*	**3.5*	---	**4.3*	**2.8*	**2.5*	**4.2*	---
			Orthocladius	*T*	*11.5*	*30.7*	*39.5*	*20.9*	*2.9*	*28.7*	*48.1*	*9.2*	*50*	---

Phylum	Order	Family	Genus	Tolerance	2009 RA	2010 RA	2011 RA	2012 RA	2013 RA	2014 RA	2015 RA	2016 RA	2017 RA	2018 RA
Arthropoda	*Diptera*	*Chironomidae*	*Parametriocnemus*	*M*	*---*	*1.8*	*---*	*---*	*5.9*	*3.5*	*0.9*	*---*	*3.3*	*4.2*
			Paratanytarsus	*T*	*---*	*---*	*---*	*---*	*---*	*---*	*---*	*---*	*---*	*42*
			Phaenopsectra	*T*	*---*	*---*	*---*	*---*	*---*	*1.7*	*---*	*---*	*---*	*---*
			Polypedilum	*M*	*2.9*	*0.9*	*8.9*	*6.1*	*1*	*0.9*	*6.5*	*16.7*	*3.3*	*---*
			Potthastia	*I*	*---*	*---*	*---*	*1.7*	*---*	*---*	*---*	*---*	*1.7*	*0.8*
			Rheocricotopus	*M*	*---*	*---*	*---*	*---*	*2.9*	*---*	*---*	*0.8*	*---*	*7.6*
			Rheotanytarsus	*T*	*---*	*---*	*0.8*	*---*	*1*	*3.5*	*---*	*---*	*---*	*---*
			Sympotthastia	*T*	*---*	*9.6*	*---*	*---*	*1*	*8.7*	*---*	*---*	*1.7*	*2.4*
			Synorthocladius	*M*	*---*	*---*	*---*	*---*	*---*	*1.7*	*---*	*---*	*---*	*---*
			Tanytarsini	*M*	*---*	*---*	*---*	*---*	*---*	*---*	**1.9*	**0.8*	*---*	*0.8*
			Tanytarsus	*M*	*---*	*---*	*---*	*---*	*1*	*0.9*	*---*	*0.8*	*---*	*---*
			Tanypodinae	*T*	*---*		*---*	*---*	*---*	*---*	**0.9*	*---*	*---*	*5*
			Thienemanniella	*M*	*---*	*0.9*	*4*	*---*	*---*	*2.6*	*---*	*---*	*---*	*---*
			Thienemannimyia Group	*T*	**1.0*	*---*	**0.8*	*---*	*---*	**0.9*	*---*	**0.8*	*---*	*---*
			Trissopelopia	*M*	*1*	*---*	*---*	*---*	*---*	*---*	*---*	*---*	*---*	*---*
			Tvetenia	*M*	*---*	*5.3*	*---*	*3.5*	*6.9*	*7*	*---*	*0.8*	*0.8*	*3.4*
			Zavrelimyia	*M*	*---*	*---*	*---*	*---*	*---*	*0.9*	*---*	*---*	*---*	*0.8*
		Empididae	*n/a*	*T*	**1.0*	**0.9*	*---*	**12.2*	*---*	*---*	**0.9*	*---*	*---*	**13.4*
			Clinocera	*T*	*4.8*	*---*	*2.4*	*1.7*	*---*	*---*	*0.9*	*0.8*	*---*	*---*
		Simuliidae	*Simulium*	*M*	*1.9*	*2.6*	*0.8*	*5.2*	*---*	*---*	*0.9*	*2.5*	*0.8*	*---*
			Prosimulium	*I*	*---*	*---*	*---*	*0.9*	*---*	*---*	*---*	*---*	*---*	*---*
		Psychodidae	*n/a*	*M*	*---*	*---*	*---*	*---*	*---*	*---*	*---*	**0.8*	*---*	*---*

Phylum	Order	Family	Genus	Tolerance	2009 RA	2010 RA	2011 RA	2012 RA	2013 RA	2014 RA	2015 RA	2016 RA	2017 RA	2018 RA
Arthropoda	*Diptera*	*Tipulidae*	*n/a*	*M*	**1.0*	---	---	---	---	---	---	---	---	---
			Antocha	*T*	---	---	---	*0.9*	---	---	*4.6*	---	---	*0.8*
			Dicranota	*I*	---	---	---	*1*	---	---	---	---	---	---
			Tipula	*M*	*1.9*	*0.9*	*0.8*	*0.9*	*3.9*	---	*1.9*	---	---	---
	Ephemeroptera	*Baetidae*	*Acentrella*	*M*	---	---	---	*3.5*	---	---	---	---	---	---
		Ephemerellidae	*Eurylophella*	*M*	*2.9*	*0.9*	---	*1.7*	*2*	---	---	*0.8*	*0.8*	---
		Heptageniidae	*n/a*	*I*	---	---	---	---	---	---	**0.9*	---	---	---
			Maccaffertium	*I*	---	---	---	---	*1*	---	*0.9*	---	---	---
	Odonata	*Gomphidae*	*Stylogomphus*	*I*	---	---	---	---	*1*	---	---	---	---	---
	Plecoptera	*Leuctridae*	*n/a*	*I*	---	---	**1.6*	---	---	---	---	**1.6*	---	---
			Leuctra	*I*	---	---	*0.8*	---	---	---	---	---	---	---
		Nemouridae	*Amphinemura*	*I*	*3.8*	---	---	*0.9*	---	---	*12*	*10.8*	*18.3*	---
	Plecoptera	*Nemouridae*	*Diplectrona*	*I*	*8.7*	*2.6*	*0.8*	---	---	---	*0.9*	*0.8*	*1.7*	*0.8*
	Trichoptera	*Hydropsychidae*	*n/a*	*M*	---	---	---	---	---	---	---	---	---	**0.8*
		Hydropsychidae	*Cheumatopsyche*	*T*	*7.7*	---	*1.6*	*2.6*	*27.5*	*8.7*	*3.7*	*7.5*	*0.8*	---
		Hydropsychidae	*Hydropsyche*	*T*	---	*1.8*	---	*0.9*	---	*0.9*	---	*5.8*	---	---
		Limnephilidae	*n/a*	*M*	---	---	---	---	---	**0.9*	---	---	---	---
			Ironoquia	*M*	*1*	---	---	---	---	---	*0.9*	---	---	---
			Pycnopsyche	*M*	---	---	*0.8*	---	---	---	---	---	---	---
		Philopotamidae	*n/a*	*I*	---	---	---	---	---	---	**1.9*	---	---	---
			Chimarra	*M*	*2.9*	*1.8*	---	---	*9.8*	*8.7*	*1.9*	*3.3*	*0.8*	*2.5*
			Dolophilodes	*I*	*4.8*	*28.9*	---	*21.7*	---	*0.9*	---	*15.8*	---	*0.8*

Phylum	Order	Family	Genus	Tolerance	2009 RA	2010 RA	2011 RA	2012 RA	2013 RA	2014 RA	2015 RA	2016 RA	2017 RA	2018 RA
Arthropoda	*Trichoptera*	*Polycentropididae*	*Polycentropus*	*I*	*3.8*	---	---	---	---	---	---	---	---	---
			Neureclipsis	*I*	---	---	---	---	*1*	---	---	---	---	---
		Psychomyiidae	*Lype*	*M*	---	---	---	---	*1*	---	---	---	---	---
		Uenoidae	*Neophylax*	*I*	---	---	---	*1*	---	---	---	---	---	---
Mollusca	*Basommatophora*	*Ancylidae*	*Ferrissia*	*T*	---	---	---	---	---	---	---	*0.8*	---	---
		Lymnaeidae	*Stagnicola*	*T*	---	---	---	---	---	---	---	*0.8*	---	---
		Physidae	*Physa*	*T*	---	---	---	---	---	---	---	---	---	*3.4*
	Veneroida	*Pisidiidae*	*n/a*	*M*	**1.0*	---	---	---	---	---	---	---	**0.8*	---
			Musculium	*M*	---	---	*0.8*	---	---	---	---	---	---	---

Tolerance values are represented as I, M, or T. Intolerant taxa with tolerance values from 0 to 3 are represented by I. Moderately tolerant taxa with tolerance values from 3.1 to 6.9 are represented by M. Tolerant genera with tolerance values from 7 to 10 are represented by T.

* Taxa not identified to genus.

WHEEL CREEK
GEOMORPHIC ASSESSMENT
POST-RESTORATION YEAR 3
FINAL REPORT

VERSAR

Your Needs. Our Mission.

HARFORD COUNTY MARYLAND

AT THE RISQUE OF OUR LIVES AND FORTUNES 1773

November 14, 2019

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WHEEL CREEK
GEOMORPHIC ASSESSMENT
POST-RESTORATION YEAR 3 FINAL REPORT

Prepared for:

Harford County
Department of Public Works
Division of Highways and Water Resources
212 South Bond Street
Bel Air, Maryland 21014

Prepared by

Versar, Inc.
9200 Rumsey Road, Suite 1
Columbia, Maryland 21045

November 14, 2019

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1.0 INTRODUCTION

Harford County Department of Public Works (DPW) has completed the restoration of the Wheel Creek watershed, which is located in the Bush River Basin in the central portion of Harford County near Bel Air (Figure 1-1). The restoration project is the result of previous planning efforts including the Bush River Watershed Restoration Strategy (WRAS), the Bush River Watershed Management Plan in 2003, and the Wheel Creek Watershed Assessment completed in 2008.

Restoration efforts in this watershed began in September 2012 with the retrofit of a stormwater management facility (Pond A) located at the Gardens of Bel Air, and construction was completed in December of 2012. A second project, the Calvert's Walk stream restoration project, began in January of 2013 and was completed that April. In 2015, two more stormwater management facilities were retrofitted, Pond C in August and Pond D in December. The final phase of implementation was completed in March of 2017. These projects included the Lower Wheel Creek stream restoration and the retrofit of the final stormwater management facility (Pond E).

As part of implementing the restoration efforts, the County was awarded funds from a Local Government Implementation Grant through the Chesapeake and Atlantic Coastal Bays 2010 and 2016 Trust Funds. Under the grant proposal, the County planned to implement a total of four stormwater retrofits and five stream restoration projects to improve water quality, decrease stormwater discharges, and improve instream habitat.

Beginning in 2009, the County initiated monitoring to demonstrate measurable reductions of sediment and nutrients, improvement in physical stability and instream habitat, and improvement in fish and benthic macroinvertebrates communities. As a collaborative monitoring effort, Harford County DPW, Maryland Department of Natural Resources (DNR), the United States Geologic Survey (USGS), and two consulting firms (KCI Technologies and Versar, Inc.) have performed select data collection activities. The study design was developed to compare Pre-Construction conditions (i.e., baseline conditions) to future Post-Construction restoration conditions. This report focuses on seven years of geomorphic monitoring, conducted by KCI and Versar. Data generated by other project partners includes:

- USGS – flow gaging at the downstream end of Wheel Creek (5-minute interval discharge record);
- Maryland DNR (Up to July 2016)/Versar (July 2016 to present) – flow gaging at three stations, one at Wheel Road and two upstream on the eastern tributary at Cinnabar Lane and Wheel Court (5-minute interval discharge record);
- Maryland DNR MBSS – Biological and physical habitat data; and
- Versar – Storm runoff water chemistry and water quality monitoring including nutrient and sediment data at three stations, one at Wheel Road and two upstream on the eastern tributary at Cinnabar Lane and Wheel Court (pollutant loads for the measured parameters for each sampled event)

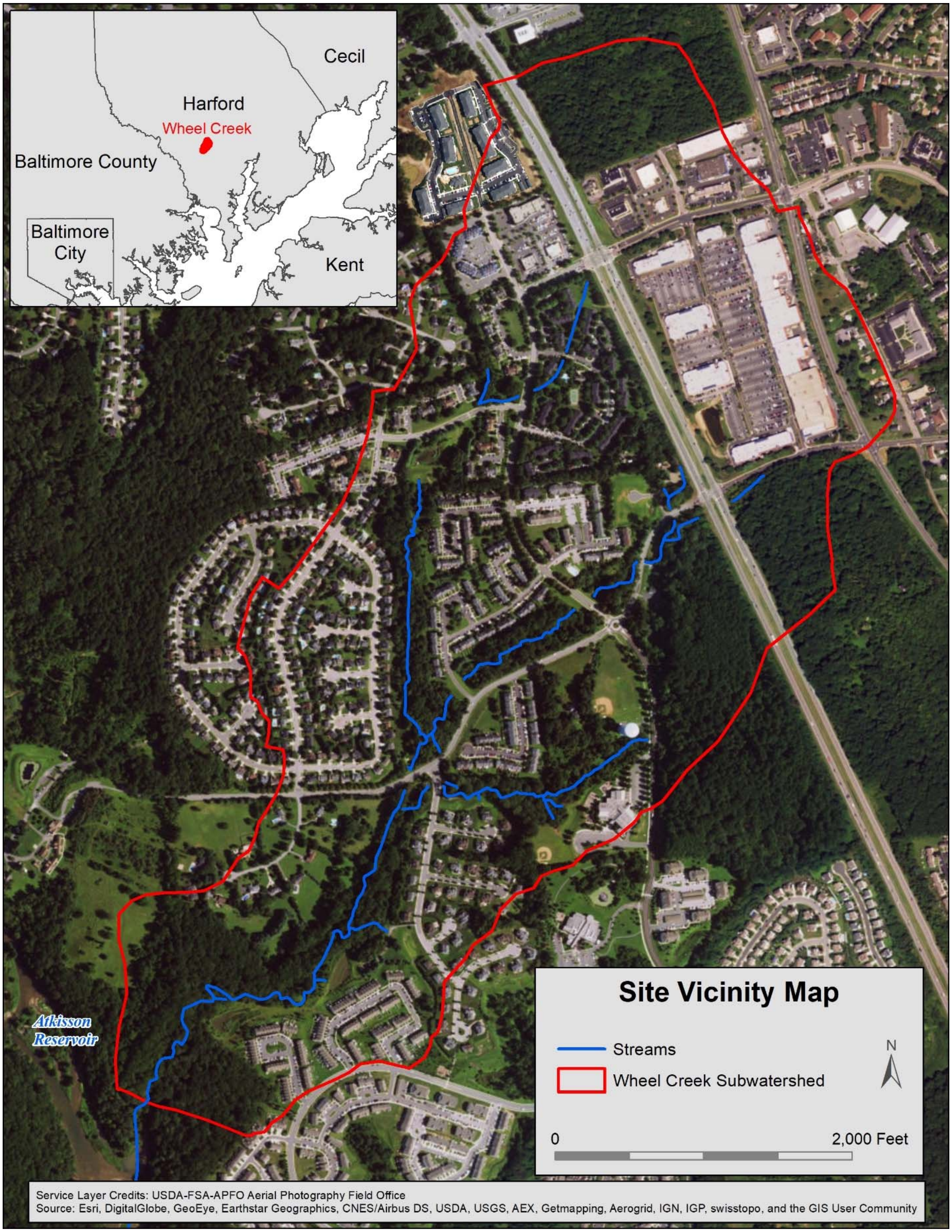

Figure 1-1. Site vicinity map

- Harford County DPW (Up to March 2019)/Versar (April 2019 to present) – Baseflow nutrient and total suspended solids data at three stations, one at Wheel Road and two upstream on the eastern tributary at Cinnabar Lane and Wheel Court.

Assessment and monitoring of the physical geomorphologic conditions was initially performed by KCI in 2010 (Pre-Restoration Year 1) to evaluate baseline conditions and was continued by Versar in 2012 (Pre-Restoration Year 2), 2013 (Pre-Restoration Year 3), 2015 (Pre-Restoration Year 4), 2017 (Post-Restoration Year 1), 2018 (Post-Restoration Year 2), and 2019 (Post-Restoration Year 3). The geomorphic monitoring program was designed to assess the geomorphic stability of the stream channels in the Wheel Creek watershed as they respond to restoration activities. The geomorphic monitoring includes surveying and analyzing monumented cross-sections and longitudinal profiles at four (4) reaches (Pre-Restoration Years 1 through 4 and Post-Restoration Years 1 through 3), monitoring bankpins and scour chains (Pre-Restoration Year 1 through 4 only), mapping substrate facies (Pre-Restoration Year 1 only), and evaluating substrate particle size distribution (Pre-Restoration Years 1 through 4 and Post-Restoration Years 1 through 3). The methods evaluate bed and bank stability, channel profile, and bed features. For a complete description of the Year 1 Study see *Wheel Creek Watershed Restoration Project, Pre-Construction Monitoring, Baseline Conditions, 2009-2011* (KCI, 2012). For a complete description of the Year 2, Year 3, and Year 4 Studies see *Wheel Creek Geomorphic Assessment Year 2* (Versar, 2013), *Wheel Creek Geomorphic Assessment Year 3* (Versar, 2014) and *Wheel Creek Geomorphic Assessment Year 4* (Versar, 2015). For a complete description of the Post-Restoration Year 1 Study see *Wheel Creek Geomorphic Assessment Post-Restoration Year 1 Final Report* (Versar, 2017), and Year 2 Study see *Wheel Creek Geomorphic Assessment Post-Restoration Year 2 Final Report* (Versar, 2018). This report focuses on continued geomorphic monitoring, including a comparison of data collected during Pre-Restoration Years 1, 2, 3, 4, and Post-Restoration Years 1, 2, and 3.

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2.0 METHODOLOGIES

2.1 GEOMORPHIC ASSESSMENT

The primary goal of the geomorphic monitoring is to assess the geomorphic stability of the stream channels in the Wheel Creek watershed as they respond to restoration activities. Assessment techniques include a survey of permanently-monumented channel cross-sections, a longitudinal profile survey, particle size analysis, substrate facies mapping (Pre-Restoration Year 1 only), and assessment of bank pins and scour chains (Pre-Restoration Years 1 through 4 only). In 2010, four (4) assessment reaches (Figure 2-1) were established by KCI for geomorphic monitoring based on the following treatments:

1. within a stream stabilization reach (WC01);
2. within a stream stabilization reach and downstream of a retrofitted stormwater management facility (WC02);
3. downstream of a retrofitted stormwater management facility (WC03); and
4. a control site with no proposed restoration activities (WC04).

These reaches were re-surveyed by Versar in 2012, 2013, 2015, 2017, 2018, and 2019 to provide additional monitoring data. Cross-sectional and longitudinal profile surveys were first conducted to establish baseline conditions of channel geometry and slope. Subsequent survey data can be compared to the baseline data to determine whether lateral or vertical migration of the channel is occurring and to document any changes that have occurred in the restored reaches. Bank and bed pins were monitored to determine rates of potential bank and channel bed erosion or aggradation, while scour chains are used to quantify the extent of bed material scouring. The bank and bed pins along with the scour chains have been discontinued from the monitoring following Pre-Restoration Year 4 (2015). Pebble counts were conducted to assess substrate particle size distribution and track changes in channel roughness. Detailed methods are described below.

2.1.1 Longitudinal Profile and Cross-sectional Surveys

KCI installed and surveyed three (3) benchmark monuments at each reach during the initial baseline monitoring effort (2010) to establish consistent survey elevations from year to year, as well as start and end points for each survey reach. Two benchmarks (one concrete monument and one capped iron rebar pin) were placed on either side of the channel, whereby a measuring tape run from the left bank pin to the right bank monument marks the starting point (i.e., station 0+00) in the channel for the longitudinal profile. The concrete monument was set in 2-inch PVC piping to a depth of 30 inches, with a rounded stove bolt set in the concrete to establish the monumented benchmark elevation, which will be used to compare longitudinal profiles over time. A third monument (capped iron rebar) was placed at the upstream end of the reach to mark the end of the survey reach. Versar re-surveyed these benchmarks at WC03 and WC04 during the Post-Restoration Years 1, 2, and 3 efforts to enable overlays between past surveys.

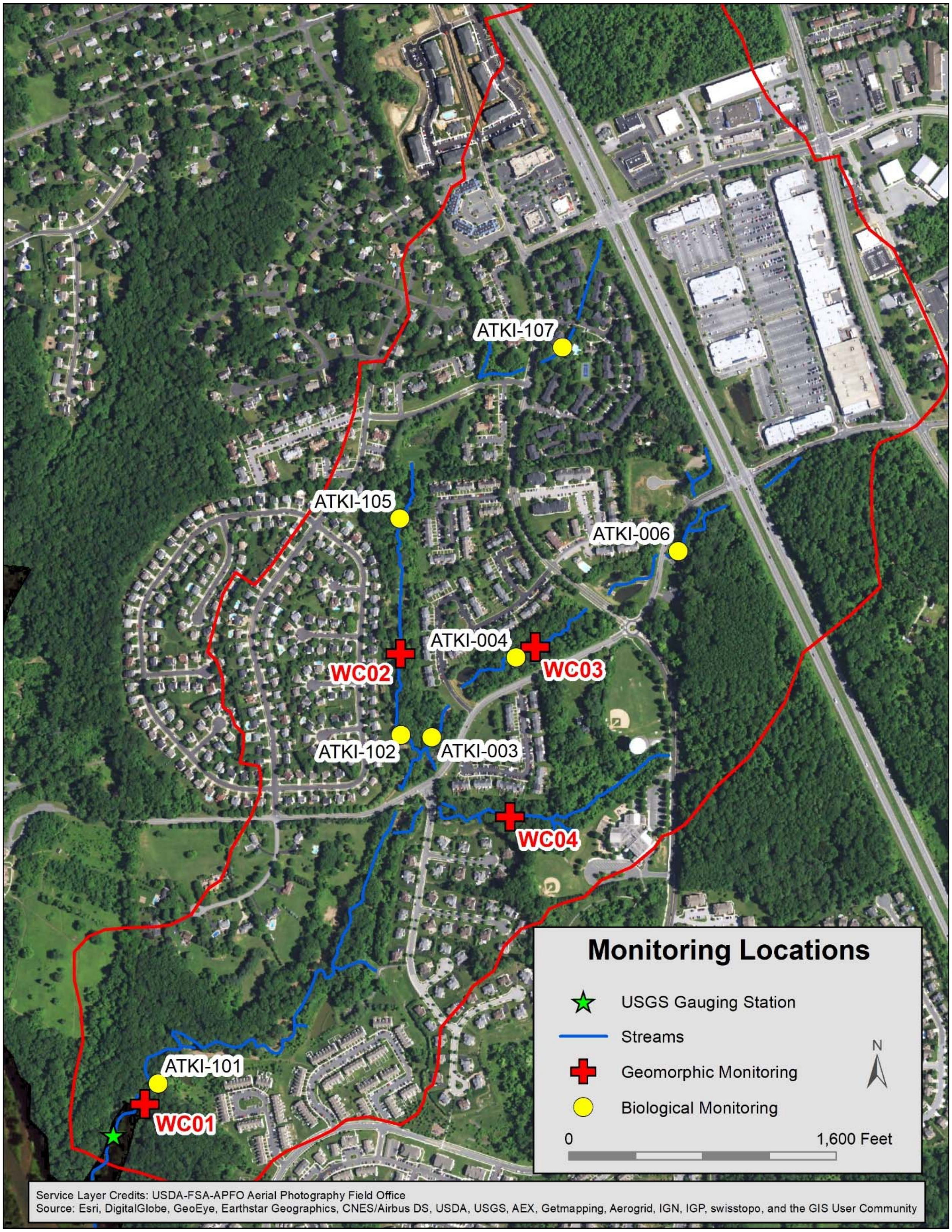

Figure 2-1. Wheel Creek monitoring locations

Versar re-established reaches WC01 and WC02 in 2017 for Post-Restoration Year 1 monitoring. Three (3) benchmark monuments were again installed at both reaches. Two capped iron rebar monuments were installed on each side of the channel to mark the starting point of the new longitudinal profile (i.e., station 0+00). An additional capped iron rebar monument was installed upstream marking the end of the longitudinal profile. These were re-surveyed in 2019.

A longitudinal profile of each reach was surveyed using a laser level, calibrated stadia rod, and 300-foot measuring tape following the procedure outlined in Harrelson et al. (1994). The longitudinal profiles were initially established to encompass a minimum reach length of approximately 20 bankfull widths or 300 feet, measured along the centerline of each bankfull channel. Each reach was started at the top of a feature located at the downstream benchmarks, and finished at the top of a feature at or above the upstream benchmark. Each reach included a survey of breakpoints in and between bed features and delineation of riffle, run, pool, and glide features. A survey of the bankfull elevation (where discernible), top of bank, and water surface was also performed. At each site where instream restoration activities did not occur (WC03 and WC04), the plotted Post-Restoration Years 1, 2, and 3 longitudinal profiles were overlaid with the plots from Pre-Restoration Years 1 through 4. These plots enable comparisons between years and are used to track changes that occur in the bed sequences and channel slopes. At the two sites where instream restoration occurred (reaches WC01 and WC02), the plotted profiles from Pre-Restoration Years 1 through 4 were overlaid and the Post-Restoration Years 1, 2, and 3 plotted profiles were compared.

In order to establish locations where fluvial geomorphic characteristics of the channel could be measured and compared from one year to the next for assessing bed and bank stability, KCI established permanent cross-sections at two (2) locations within each monitoring reach during Pre-Restoration Year 1; one located on a meander bend and one within a riffle feature. KCI established monuments (one concrete and one capped iron rebar) on either side of the channel to mark the cross-section locations and benchmark elevations. Concrete monuments were set in 2-inch PVC piping to a depth of 30 inches, with a rounded metal stove bolt set in the concrete to mark the monumented elevation. Wherever possible, the monuments were set flush to the ground surface for safety concerns, and the location of each monument was recorded using a GPS unit capable of sub-meter accuracy.

Permanent cross-sections were established in 2010 and surveyed during Pre-Restoration Years 1, 2, 3, 4, and Post-Restoration Years 1, 2 and 3 within each reach at profile stations as shown in Table 2-1. Stationing differed slightly at several stations due to channel migration over time or as a result of re-installing a cross-section when instream restoration has occurred. Cross-sections located in reaches WC01 and WC02 were re-established with new benchmarks in Post-Restoration Year 1 (2017). Due to ongoing restoration construction activities, the WC01 left end pin at Cross-section 2 had to be reinstalled in 2018, as it could not be located during the Post-Restoration Year 2 survey. Reaches WC03 and WC04 were still monumented to the original benchmarks installed in Pre-Restoration Year 1 (2010) since no instream restoration occurred at those locations. However, the WC03 right end pin at Cross-section 2 had to be reinstalled in 2019, as it had eroded away and fallen into the stream channel during the Post-Restoration Year 3 survey. The same methods were used to establish the new cross-sections in these reaches, although the corresponding station on the longitudinal profile will not be comparable to previous years of Pre-Restoration surveying.

Table 2-1. Cross-sectional survey locations

Reach	WC01*		WC02*		WC03		WC04	
Profile Station (Pre-Year 1)	2+30	2+95	1+37	3+24	1+55	2+07	1+08	1+68
Profile Station (Pre-Year 2)	2+30	2+95	1+38	3+24	1+57	2+08	1+08	1+68
Profile Station (Pre-Year 3)	2+29	2+95	1+38	3+25	1+56	2+12	1+08	1+68
Profile Station (Pre-Year 4)	2+29	2+95	1+38	3+24	1+55	2+07	1+08	1+68
Profile Station (Post-Year 1)	2+24	2+71	0+74.5	1+10	1+56	2+08	1+10	1+68
Profile Station (Post-Year 2)	2+24	2+71	0+74.5	1+10	1+56	2+08	1+10	1+68
Profile Station (Post-Year 3)	2+24	2+71	0+74.5	1+10	1+56	2+08	1+10	1+68
Feature	Riffle	Meander/ Pool	Riffle	Pool	Riffle	Meander/ Run	Meander/ Pool	Riffle

*Cross-sections re-established during Post-Restoration Year 1

During Post-Restoration Year 3, Versar resurveyed the cross-sections using a laser level, calibrated stadia rod, and measuring tape following the procedure outlined in Harrelson et al. (1994). The cross-sectional surveys captured features of the floodplain, monuments, and all pertinent channel features including:

- Top of bank
- Bankfull elevation
- Edge of water
- Limits of point and instream depositional features
- Thalweg
- Floodprone elevation

Longitudinal profile and cross-sectional data were entered into *The Reference Reach Spreadsheet* version 4.3L (ODNR, 2012) for data analysis and graphical interpretation. Profile and cross-sectional data collected in 2010, 2012, 2013, 2015, 2017, 2018, and 2019 provide seven years of data to which subsequent monitoring events will be overlaid and/or compared to assess changes in channel dimension, pattern, and profile.

For the purpose of this report, bankfull elevations were selected based upon bankfull indicators observed in the field. Channel geometry and cross-sectional areas were calculated using *The Reference Reach Spreadsheet* (ODNR, 2012). Because bankfull indicators are not always easily discernible from year to year and best professional judgment is often required to determine bankfull elevations, top of bank features were also measured. Top of low bank cross-sectional areas were also calculated and can be utilized for future monitoring events to generate hydraulic geometry values that are more directly comparable between each monitoring effort.

2.1.2 Particle Size Analysis

Channel substrate composition (e.g., gravel, sand, silt) is an important aspect of a stream's biological and geomorphic character. The substrate size and complexity affects the stream's available habitat for benthic fauna and determines a channel's roughness, which influences the channel flow characteristics. To quantify the distribution of channel substrate particle sizes within the study area, modified Wolman pebble counts (Wolman, 1954; Harrelson et al., 1994) were performed. A total of three (3) pebble counts were conducted within each monitoring reach; feature-specific pebble counts were conducted at each cross-section location within the cross-sectional bed feature (typically riffles), and a weighted pebble count was conducted throughout the entire reach based on the proportion of bed features (e.g., riffle, run, pool, glide) present within the survey reach. Feature-specific pebble counts were performed via 10 evenly-spaced transects positioned throughout the survey feature, and 10 particles (spaced as evenly as possible) were measured across the bankfull channel of each transect for a total of 100 particles. The weighted (proportional) pebble count was conducted at 10 transects positioned throughout the entire reach based on the proportion of bed features, and 10 particles (spaced as evenly as possible) were measured across the bankfull channel of each transect for a total of 100 particles. For both types of counts, particles were chosen without visual bias by reaching forth with an extended finger into the stream bed while looking away and choosing the first particle that comes in contact with the sampler's finger. All particles were then measured across the intermediate axis using a gravelometer and resultant data were entered into *The Reference Reach Spreadsheet* (ODNR, 2012). The results of each weighted pebble count were used to determine the median particle size (i.e., D_{50}) of the specific reach. Additionally, the D_{84} was calculated from the feature pebble counts to determine the particle size that 84 percent of the sample is of the same size or smaller. The D_{84} particles were used in calculating channel velocity and discharge. Results from Versar's Post-Restoration Year 3 evaluations were compared to those found during the previous years of monitoring to evaluate changes in channel substrate composition and stability.

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3.0 RESULTS AND DISCUSSION

3.1 FLUVIAL GEOMORPHIC ASSESSMENT

3.1.1 Longitudinal Profiles and Cross-sectional Surveys

The third year of Post-Restoration longitudinal profile and cross-sectional surveys was completed between May 1st and May 3rd, 2019. While performing the longitudinal profile, bed features including riffles, runs, pools, glides, bankfull indicators (where readily discernible), and water surface were noted to sufficiently assess conditions. The longitudinal profile data were analyzed to calculate the water surface slope and proportion of bed features for each monitoring reach (Table 3-1). These data will be compared to previous and subsequent annual monitoring data to track potential changes in the overall channel slope. Refer to Appendix A for photographs depicting the overall site conditions during the Post-Restoration Year 3 survey. Graphical depictions of each profile are presented in Appendix B. In addition, each surveyed profile was plotted, but only overlain and compared to the Pre-Restoration Years 1, 2, 3, and 4 profiles at WC03 and WC04 (Appendix C) and will be compared to subsequent annual surveyed profiles in order to assess changes occurring in the bed structure. Due to instream restoration activities, WC01 and WC02 Post-Restoration overlays do not share the same monuments as Pre-Restoration. Therefore, separate Post-Restoration overlays were created for these reaches.

Table 3-1. Results of longitudinal profile survey – Post-Restoration Year 3

Reach	Length (ft)	Slope	Proportion of Features			
			Riffle	Run	Pool	Glide
WC01*	490	2.7%	46.6%	12.7%	29.4%	11.3%
WC02*	320	2.2%	47.6%	13.9%	26.4%	12.1%
WC03	308	1.8%	46.0%	16.3%	28.1%	9.6%
WC04	300	3.3%	70.0%	8.7%	13.3%	8.0%

*Profiles re-established during Post-Restoration Year 1

Cross-sectional surveys were analyzed at each of the eight permanent monitoring locations to determine bankfull width, mean depth, width/depth ratio, and overall cross-sectional area during baseline conditions. Since bankfull elevation is based on field indicators and can be somewhat subjective to determine in the field, top-of-bank elevation was also calculated and will be utilized to track changes in the cross-sectional dimensions listed below. Results of the cross-sectional measurements are included in Table 3-2 and graphical depictions of each section are presented in Appendix B. In addition, each surveyed section was plotted, overlain (where appropriate) and compared to the Pre-Construction year 1, 2, 3, and 4 graphs (Appendix C) and will be compared to subsequent annual cross-section graphs in order to assess changes to channel dimensions post-restoration.

Table 3-2. Results of cross-sectional survey analysis – Post-Restoration Year 3								
Reach	**Station**	**Feature**	**Bankfull Width (ft)**	**Mean Depth (ft)**	**Width/ Depth Ratio**	**Entrench-ment Ratio**	**Bankfull Area (ft^2)**	**Top of Bank Area (ft^2)**
WC01*	2+24	Crossover/Riffle	28.8	0.7	41.2	1.4	20.1	161.7
	2+71	Meander/Pool	20.3	1.5	13.5	2.0	30.6	223.0
WC02*	0+74.5	Crossover/Riffle	16.2	0.6	28.5	1.4	9.2	48.4
	1+10	Pool	12.6	0.7	17.4	1.3	9.1	38.4
WC03	1+56	Crossover/Riffle	10.4	0.9	11.7	1.3	9.2	42.3
	2+08	Meander/Run	11.6	0.7	15.9	1.6	8.5	62.6
WC04	1+10	Meander/Pool	11.6	0.4	28.8	2.7	4.7	90.7
	1+68	Crossover/Riffle	9.7	0.4	24.1	1.4	3.9	56.0
*Cross-sections were re-established during Post-Restoration Year 1								

3.1.2 Particle Size Analysis

The results of the pebble count data collected during the Post-Restoration Year 3 monitoring are shown in Table 3-3. Reachwide and riffle surface pebble counts indicate a D_{50} median particle size class ranging from coarse gravel to very coarse gravel across all sites. Meander feature surface pebble counts indicate a D_{50} ranging from very coarse sand to coarse gravel, due to pool features yielding smaller particles which is especially evident at the control WC04 meander/pool cross-section. Riffle surface and reachwide D_{84} size classes range from small cobble to medium cobble at all sites, with the largest particles found at sites WC01 and WC02. Similarly, meander feature surface pebble counts at all sites indicate a D_{84} median particle size class ranging from coarse gravel to small cobble. Complete particle size distribution charts are included in Appendix B.

Table 3-3. Particle size distribution – Post-Restoration Year 3								
Riffle Feature Surface			***Meander Feature Surface***			***Reachwide***		
Measure	**Size (mm)**	**Size Class**	**Measure**	**Size (mm)**	**Size Class**	**Measure**	**Size (mm)**	**Size Class**
*WC01**								
D_{50}	47	very coarse gravel	D_{50}	12	medium gravel	D_{50}	37	very coarse gravel
D_{84}	110	medium cobble	D_{84}	51	very coarse gravel	D_{84}	90	small cobble
*WC02**								
D_{50}	51	very coarse gravel	D_{50}	16	medium gravel	D_{50}	22	coarse gravel
D_{84}	110	medium cobble	D_{84}	64	small cobble	D_{84}	76	small cobble
WC03								
D_{50}	45	very coarse gravel	D_{50}	23	coarse gravel	D_{50}	22	coarse gravel
D_{84}	88	small cobble	D_{84}	70	small cobble	D_{84}	80	small cobble
WC04								
D_{50}	27	coarse gravel	D_{50}	1.2	very coarse sand	D_{50}	23	coarse gravel
D_{84}	80	small cobble	D_{84}	29	coarse gravel	D_{84}	81	small cobble

4.0 COMPARISONS BETWEEN YEARS

4.1 WC01

This site exhibited the most drastic changes in longitudinal profile over the four years of Pre-Restoration monitoring (2010-2015; Figure C-1). At the downstream-most part of the reach, the stream's thalweg followed along the left bank outside bend during the first year of survey with a large mid-channel bar separating the thalweg from a cutoff channel along the right bank. During the second and third years of monitoring (2012, 2013), the thalweg followed what had been the cutoff channel along the right bank and the previous thalweg channel had only minimal flows. During the fourth year of survey (2015) the thalweg continued to follow the channel along the right bank. Furthermore, a large tree along the left bank fell and was perpendicularly positioned in the stream through this section. The tree caused the stream to widen and flow over most of the mid-channel bar; however, over the three years of Post-Restoration monitoring, the tree has migrated onto the left bank, laying parallel, and the outside left bend channel now conveys the majority of stream flow. At the upstream-most part of the reach, the stream's pattern also changed. Stationing differed from above Cross-section 2 (Station 2+95) to the end of the reach. During the first year of monitoring (2010), the reach was 400 feet from top to bottom, but during all other years of Pre-Restoration monitoring the reach was 420 feet in length. Sinuosity above Cross-section 2 likely increased, adding length to the profile.

Changes in the cross-sections were also observed at WC01 between the four years of Pre-Restoration survey (Figures C-7, C-9). Bed scour was observed at Cross-section 1 (Crossover Riffle at Station 2+29) especially near the right bank between Pre-Restoration Years 1 and 2, while deposition was apparent near the left bank between Pre-Restoration Years 2 and 3. During Pre-Restoration Year 4, continued deposition was observed, and the cross-section once again closely resembled that of Pre-Restoration Year 1. Significant bank erosion and undercutting along the left bank (almost 6 feet) was observed at Cross-section 2 (Meander Bend at Station 2+95) during both the second and third years of monitoring (2012, 2013). Between Pre-Restoration Years 3 and 4, continued erosion occurred along the left bank increasing the depth of undercutting. Eroded sediment caused slight deposition along the left stream bed. This resulted in increases, from Pre-Restoration Year 1, of bankfull cross-sectional area and top of bank cross-sectional area at this station. Between Pre-Restoration Years 1 and 2, a side-bar formed on the right bank, burying the scour chain at this cross-section. The scour chain was not found during Pre-Restoration Years 3 and 4 of monitoring. In addition, the thalweg pattern changed between Pre-Restoration Years 1 and 2 so that it was no longer perpendicular to the permanently monumented cross-section markers at this location.

The first year of Post-Restoration monitoring was completed in 2017. The WC01 reach underwent an instream restoration and a new longitudinal profile and two cross-sections were selected and monitored for baseline conditions. Cross-section 1 was placed in a crossover riffle at Station 2+24, while Cross-section 2 was placed at a meander bend/pool at Station 2+71. The longitudinal profile extends 490 feet through the restored reach in Harford Glen. The survey of the longitudinal profile consisted of large riffle and pool features. During 2017, approximately 55.1%

of the reach was riffle/run and 44.9% was pool/glide; in 2018, approximately 57.0% of the reach was riffle/run and 43.0% was pool/glide. During 2019, approximately 59.3% of the reach was riffle/run and 40.7% was pool/glide. The slope of the reach was high at 2.6% in 2017 and remained high at 2.7% in 2018 and 2019. The cross-sections featured stable banks exhibiting no erosion. Cross-section 1 at Station 2+24 has a defined bench and access to a small floodplain as the banks have been graded back during construction (Figure C-8). Cross-section 2 at Station 2+71 exhibits the same floodplain on the right bank in addition to a point bar, while the left bank is heavily armored by boulders (Figure C-10). Channel alterations were noted between the 2017 and 2018 Post-Restoration surveys. Minimal scouring (approximately 0.25 feet) of the channel at Cross-section 1 was observed, while significant aggradation of sediment was found along the right bank and channel at Cross-section 2. These changes in streambed were likely the result of an abnormally wet spring, and year overall, which shifted and transported large amounts of sediment throughout the reach. Between the 2018 and 2019 Post-Restoration surveys, channel alteration was again noted. Aggradation of approximately 1.0 feet occurred in the middle of the channel at Cross-section 1, and approximately 0.5 feet of scouring of the bench on the right bank was observed; significant aggradation of sediment was found along the right bank and channel at Cross-section 2. The changes in streambed were significant between 2019 and prior year surveys, likely the result of an extensive rains which shifted and transported large amounts of sediment throughout the reach. Future surveys will be useful in determining how the stream channel reacts to these changes, as well as how it stabilizes over time.

At WC01, D_{50} particle size classes remained the same between all four years of Pre-Restoration study at both cross-sections, and reachwide (Table C-3). D_{84} particle size classes changed between Years 1 and 2, coarsening at Cross-section 1 (Crossover Riffle at Station 2+29) from medium to large cobble, and becoming slightly finer at Cross-section 2 (Meander Bend at Station 2+95) from medium to small cobble. Although D_{84} classes at Cross-section 2 were unchanged between Years 2 and 3 they transformed during the fourth year of study, increasing from small cobble to medium cobble. Reachwide D_{84} particle size class fluctuated between large cobble during Year 1, to medium cobble during Year 2 and back to large cobble during Years 3 and 4. In the first year of Post-Restoration (2017), D_{50} particle sizes decreased from very coarse gravel to medium gravel at the meander feature and from very coarse gravel to coarse gravel reachwide. In Post-Restoration Years 2 and 3, reachwide D_{50} particle sizes increased back to very coarse gravel reachwide, but fluctuated between medium and very coarse gravel at the meander feature. Riffle feature surface D_{50} particle sizes remained as very coarse gravel during all 3 years of post-restoration monitoring. Reachwide D_{84} decreased to small cobble. The new crossover riffle at Station 2+24 had a D_{84} of small cobble and the new meander bend/pool at Station 2+71 had a D_{84} of very coarse gravel. In 2018, the reachwide D_{84} increased to large cobble. The new crossover riffle at Station 2+24 had an increased D_{84} to large cobble and the new meander bend/pool at Station 2+71 had an increased D_{84} to medium cobble. In 2019, the reachwide D_{84} decreased to small cobble. The new crossover riffle at Station 2+24 had a decreased D_{84} to very coarse sand and the new meander bend/pool at Station 2+71 had a decreased D_{84} to medium gravel. This overall decrease in particle size classes at WC01 was likely the result of an increase in smaller particles being transported and deposited into the reach from the above average rainfall received between 2018 and 2019.

4.2 WC02

Significant changes in profile were not observed at WC02 over the four years of Pre-Restoration study. The most noticeable change is a pool feature once approximately at Station 1+00 changed to Station 0+80 (Figures C-3 and C-4). Reach length remained constant and stream slope measurements were fairly consistent overall. Feature proportions within the reach have fluctuated from year to year. While the percentage of glides increased from 0% to 16.7% between Pre-Restoration Years 1 and 2, the percentage of pools declined each year. During the fourth year (2015), 25.5% of the surveyed reach was classified as pools and glides, the lowest percentage since monitoring began. In contrast, riffles and runs made up 74.5% of the surveyed reach which was the greatest percentage of all four years (Table C-1).

Following Pre-Restoration Year 1, bed aggradation occurred at Cross-section 1 (Crossover Riffle at Station 1+38), but banks here remained relatively stable (Figure C-11). There was little change between the third and fourth year of Pre-Restoration study. Conversely, channel scour occurred at Cross-section 2 (Meander Bend at Station 3+24), as well as slight erosion of the upper portion of the right bank (Figure C-13). At this station, a bankfull bar exists along the left bank which showed little change between Pre-Restoration Years 2 and 3 of the study. However, during the fourth year of Pre-Restoration monitoring slight degradation can be seen along the left bank and bar.

In the first year of Post-Restoration monitoring, the WC02 reach consisted of 63.6% riffle/run and 36.4% pool/glide (Table C-1). This reach consisted of 60.3% riffle/run and 39.7% pool/glide in the 2018 Post-Restoration monitoring. During 2019 Post-Restoration monitoring, this reach consisted of 61.5% riffle/run and 38.5% pool/glide. This reach underwent instream restoration that has straightened the channel causing the meander bend cross-section to be placed in a straight pool. Overall, this reach is still somewhat lacking access to an immediate floodplain, but the banks are stable and well-vegetated despite being steep and high. The entrenchment ratio was low, 1.3, in 2017, and remained low at 1.4 in 2018 and 2019, indicating the stream is confined within the banks (Appendix B). The stream is comprised predominately of long riffles and grade control steps into long/wide pools. Cross-section 1 was newly monumented in a pool at Station 0+74.5 (Figure C-12) and Cross-section 2 was monumented at Station 1+10 in a crossover riffle (Figure C-14). Both cross-sections exhibit little bank erosion and have stable banks. Cross-section 1 aggraded substantially in 2018, with more than 1.5 feet of substrate deposited in the stream channel; significant aggradation continued in 2019, with an additional 0.5 feet of sediment deposited in the stream channel. Cross-section 2 had minimal scouring (0.25 to 0.5 feet) within the channel in 2018, but experienced aggradation of 0.25 to 1.0 feet of substrate in 2019. These changes in streambed could be the result of an abnormally wet year overall between 2018 and 2019, which likely shifted and transported large amounts of sediment throughout the reach. Future surveys will enable evaluation of how the stream channel reacts to these changes, as well as how it stabilizes over time.

D_{50} particle size classes remained the same between all four years of Pre-Restoration study at both cross-sections. The reachwide D_{50} for Pre-Restoration Years 2 and 3 were categorized as coarse gravel which is slightly finer than the very coarse gravel observed in Pre-Restoration

Years 1 and 4 (Table C-3). D_{84} particle size classes became slightly finer at both cross-sections, diminishing from medium-sized cobble to small cobble between the first and second years of Pre-Restoration study. Furthermore, both cross-section D_{84} classes coarsened between Pre-Restoration Years 3 and 4 from small cobble to medium cobble. Although reachwide D_{84} particle sizes also reduced between Pre-Restoration Years 1 and 2, particles increased back to medium-sized cobble in Pre-Restoration Year 3 and remained during Pre-Restoration Year 4.

In the first year of Post-Restoration study (2017), D_{50} particle size classes decreased at both cross-sections and reachwide, classifying as coarse gravel at the riffle feature, very fine gravel at the meander feature, and medium gravel reachwide. Riffle feature D_{50} classification rebounded back into the very coarse gravel category in the Post-Restoration Years 2 and 3 surveys, and meander feature D_{50} particle sizes coarsened to small cobble in 2018 and medium gravel in 2019. Reachwide D_{50} classifications rated as coarse gravel in both Post-Restoration Years 2 and 3 surveys, coarser than the initial particle class determined by the Post-Restoration Year 1 survey, but still finer than pre-restoration ratings. Reachwide D_{84} decreased to medium gravel. The new crossover riffle at Station 1+10 had a D_{84} of very coarse gravel and the new meander bend/pool at Station 0+74.5 had a D_{84} of medium gravel. In the 2018 Post-Restoration study, the reachwide D_{84} increased to coarse gravel. The new crossover riffle at Station 1+10 had an increased D_{84} to medium cobble and the new meander bend/pool at Station 0+74.5 had an increased D_{84} to large cobble. In the 2019 Post-Restoration study, the reachwide D_{84} increased to small cobble. The D_{84} at the new crossover riffle at Station 1+10 remained as medium cobble and the new meander bend/pool at Station 0+74.5 had a decreased D_{84} to small cobble.

4.3 WC03

Pool and glide features have previously dominated reach WC03, as 65.6% and 67.5% of the reach was made up of pools and glides during Pre-Restoration Years 1 and 2, respectively. During Pre-Restoration Year 3, however, riffles and runs made up more than half (53.1%) of the reach (Table C-1). Pools and glides were dominant during Pre-Restoration Year 4 (58.5%). Changes in longitudinal profile were noted between the four years' of Pre-Restoration study, most notably the deepening of most pools reachwide between the first two years (Figure C-5). Pool depth has stayed consistent from Pre-Restoration Year 2 through Year 4 except for the pool feature at station 1+00 which has deepened about a foot.

In Post-Restoration Year 1 (2017), WC03 consisted of 66.0% riffle/run and 34% pool/glide which shows a large change from Pre-Restoration Year 4 (2015) when pools and glides were dominant. These percentages were similar in subsequent surveys, with the reach consisting of 62.7% riffle/run and 37.2% pool/glide in 2018 and 62.3% riffle/run and 37.7% pool/glide in 2019. No instream restoration occurred on this reach and the stream had aggraded over time prior to 2018 (Figure C-5). Many of the pools became shallower due to this aggradation and some transitioned into riffles or runs altogether. Slight scouring was noted in this reach during the 2018 survey when compared to prior monitoring, mostly constrained to the upper 100 feet of the profile. This scouring continued in 2019, and was evident throughout the reach instead of constrained to the upper 100 feet of the profile, likely due to above average rainfall between 2018 and 2019 which transported substrate out of the reach.

Cross-section 1 (Station 1+55) had been a crossover riffle when initially established during Pre-Restoration Year 1 of the study and again in Pre-Restoration Years 3 and 4. However, changes in channel profile resulted in the riffle feature migrating downstream, and this cross-section was within a pool feature when surveyed in Pre-Restoration Year 2 (Figure C-5). As a result, Year 2 bankfull cross-sectional dimensions changed significantly at this station, with the deepening of the channel bed (Table C-2). The Pre-Restoration Year 4 streambed most closely resembled that of the Pre-Restoration Year 2 study. The right streambank remained relatively unchanged at Cross-section 1 throughout the four-year Pre-Restoration study while the left bank slightly filled in between 2012 and 2015 (Figure C-15). Significant deepening also occurred at Cross-section 2 (Meander Bend at Station 2+07), and erosion of the outside (left) bank was also observed between Pre-Restoration Years 1 and 2 (Figure C-16). The left bank continued to erode between Pre-Restoration Years 2 and 3 while aggradation occurred in the stream bed near the left bank. Significant erosion continued on the left bank between Pre-Restoration Years 3 and 4 as well as scouring of the left bank streambed. Consequently, bankfull cross-sectional dimensions and entrenchment ratios also differed significantly at this station between all four Pre-Restoration years (Table C-2).

In the first year of Post-Restoration monitoring, Cross-section 1 at Station 1+56 continued eroding slightly on the left bank while the right bank aggraded around the toe of the bank almost 0.5 feet (Figure C-15). In 2018, the left bank stabilized, while scouring occurred around the toe of both the left and right banks. Erosion of the left bank was evident again during the 2019 survey while the toe of the left bank aggraded; measurements across the right bank demonstrated that it has remained stable. Cross-section 2 at Station 2+08 has undergone major changes since Pre-Restoration Year 4 (2015). The left bank has eroded an additional 2 to 3 feet from 2015 to 2019 and has undercut the bank; the left bank at Cross-section 2 eroded away enough between 2018 and 2019 to cause the left end pin of the cross-section to fall into the stream channel, making it necessary for the field crew to install a new end pin further up the bank (Figure C-16). The streambed at this cross-section continues to scour significantly on the left side of the channel and aggrade on the right side of the channel due to the encroaching point bar.

At Cross-section 1 (crossover riffle at Station 1+55), channel substrate became more fine, with the D_{50} decreasing from very coarse gravel to coarse gravel between Pre-Restoration Years 1 and 3 (Table C-3). During Pre-Restoration Year 4, D_{50} increased and was once again categorized in the very coarse gravel size class. The D_{84} decreased from small cobble to very coarse gravel and back to small cobble over the four years of Pre-Restoration monitoring. In Post-Restoration Year 1, the D_{50} decreased to coarse gravel and the D_{84} remained very coarse gravel. In Post-Restoration Year 2, the D_{50} remained coarse gravel and the D_{84} increased to small cobble. The D_{84} also decreased at Cross-section 2 (Meander Bend at Station 2+07) from small cobble in Pre-Restoration Year 1 to very coarse gravel in Pre-Restoration Years 2 and 3 to coarse gravel in Pre-Restoration Year 4. At Cross-section 2, D_{50} particle size classes remained the same between the first two years of Pre-Restoration study (medium gravel) and increased during the third (coarse gravel). During the fourth Pre-Restoration year, D_{50} size decreased from coarse gravel to fine gravel. In Post-

Restoration Years 1 and 2, the D_{50} increased to medium gravel and the D_{84} increased to very coarse gravel. Reachwide, the D_{50} was coarse gravel during three of the four Pre-Restoration study years with a slight increase to very coarse gravel occurring in Year 3. The D_{84} showed the same pattern as the D_{50}, increasing only during Pre-Restoration Year 3 to large cobble and remaining in the same small cobble class Pre-Restoration Years 1, 2, and 4. During the first Post-Restoration year (2017), the reachwide D_{50} was medium gravel and D_{84} was very coarse gravel; the reachwide D_{50} increased to coarse gravel in 2018, and D_{84} remained very coarse gravel, continuing the trend to smaller material than in years past. The reachwide D_{50} remained as coarse gravel in 2019, and D_{84} increased to small cobble, discontinuing the trend to smaller materials from years past. Future monitoring is needed to determine if the particle size distribution is stabilizing in this reach, or if continued erosion will result in shifting particle size distributions throughout this reach.

4.4 WC04

No significant changes were observed in the profile of the downstream portion of the reach at site WC04 between the four years of Pre-Restoration study. However, during Pre-Restoration Years 2 through 4 surveys and the Post-Restoration Year 1 survey, the stream channel was dry from above the pool feature at Station 1+80 to the top of the reach at Station 3+00 and beyond; the streambed was found to be mostly dry from Station 2+50 to the top of the reach in the Post-Restoration Year 2 survey. Around this same station and above, channel aggradation can be seen when comparing the profiles of the initial year and all the following years' surveys (Figure C-6) which may explain the decrease in water depth between these surveys. While no significant channel alterations were noted during the Post-Restoration Year 3 survey in 2019, this reach was found to have water throughout the entire longitudinal profile; further studies are needed to determine if the increased extent of water will remain permanent at WC04 or if it was the result of above normal rainfall between 2018 and 2019 and will dry up in future years. Reach length, slope, and proportion of features within the reach remained relatively unchanged (Table C-1).

The cross-sections within this reach also remained relatively unchanged between the first three years of Pre-Restoration study, with the exception of some lower bank erosion observed at Cross-section 1 (Meander at Station 1+08) between Pre-Restoration Years 1 through 3 (Figure C-17). During Pre-Restoration Year 4, erosion on the lower left bank continued and was more apparent resulting in higher bankfull and width depth dimensions. This station was identified as a riffle located just above the top of a pool during the initial year of Pre-Restoration monitoring, but was within part of the pool when surveyed in all other subsequent Pre-Restoration years. The channel was actively widening and cutting into the bank at this station during the Pre-Restoration Year 4 survey, resulting in changes in cross-sectional dimensions. This undercutting continued to take place in Post-Restoration Years 1 through 3 (Table C-2). The overall top of bank area slightly decreased again in 2019, due to the growing point bar and bench, while bankfull area slightly increased from the 2018 survey (Figure C-17). Cross-section 1 at Station 1+10 is now in a meander pool feature in Post-Restoration Years 1 and 2, a change from the original riffle feature in Pre-Restoration Year 1 and the pool feature in Pre-Restoration Years 2 through 4 (Table C-2). Cross-section 2 at Station 1+68 remains unchanged and stable, with slight aggradation occurring on the right side of the channel in Post-Restoration Years 1 and 2 (Figure C-18).

Reachwide D_{84} particle size classes remained the same during all four Pre-Restoration years (small cobble), decreased in Post-Restoration Years 1 and 2 to very coarse gravel, and increased back to small cobble in Post-Restoration Year 3 (Table C-3). D_{84} remained the same at Cross-section 1 during the first three years of Pre-Restoration study (small cobble) and decreased during the fourth year to coarse gravel, where it remained in Post-Restoration Year 1. An increase in D_{84} to very coarse gravel was noted at Cross-section 1 in 2018, and again to small cobble in 2019. At Cross-section 2, D_{84} decreased from small cobble to very coarse gravel between Pre-Restoration Years 2 and 3. It increased back to small cobble between Pre-Restoration Years 3 and 4 and had remained small cobble through Post-Restoration Year 2. D_{84} decreased from small cobble to coarse gravel between Post-Restoration Years 2 and 3 (Table C-3).

Reachwide D_{50} particle size class increased from coarse gravel to very coarse gravel between Pre-Restoration Years 2 and 3 and decreased back to coarse gravel during Pre-Restoration Year 4 for the reachwide survey. During the Post-Restoration Year 1 survey, the reachwide D_{50} slightly decreased to medium gravel, but increased back to coarse gravel in the 2018 and 2019 studies (Table C-3). Cross-section 1 D_{50} has fluctuated by decreasing from medium gravel to very coarse sand and again increasing to medium gravel and Cross-section 2 remained the same (very coarse gravel) between Pre-Restoration Years 2, 3, and 4. In Post-Restoration Year 1, the D_{50} at Cross-section 1 remained medium gravel while the D_{50} at Cross-section 2 decreased to coarse gravel. Post-Restoration Year 2 results showed that the D_{50} at Cross-section 1 decreased again to very coarse sand while the D_{50} at Cross-section 2 increased back to very coarse gravel. Post-Restoration Year 3 results showed that the D_{50} at Cross-section 1 remained as very coarse sand while the D_{50} at Cross-section 2 decreased to coarse gravel (Table C-3).

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5.0 CONCLUSIONS

The data presented herein provide an assessment of geomorphic conditions within the Wheel Creek watershed prior to and following completion of restoration efforts. During the Pre-Restoration Years 1 and 2 studies, none of the planned restoration projects had been completed within this watershed. During the Pre-Restoration Year 3 study, two planned restoration projects had been constructed while the remaining projects were still in planning stages. Continued planning occurred during Pre-Restoration Year 4 but no new construction activities were initiated. Restoration activities were all completed as of the Post-Restoration Year 1 survey, thus this year's survey is the third annual assessment following completion of restoration. Results of the geomorphic monitoring show that bank erosion continues to be prevalent in the two reaches (WC03, WC04) that did not receive stream restoration, but has improved in those reaches where instream channel restoration activities took place (WC01, WC02). Erosion of stream banks not only increases the sediment supply to the watershed but also provides a potential source of nutrients, especially phosphorus. Stream bank erosion is a common symptom of streams like those in Wheel Creek, where urban land cover is dominant (46.1%), contributing large amounts of impervious cover (21.4%) to the watershed (Becker, 2011). Efforts have been made to decrease the impact of damaging storm water flow causing erosion among the unstable banks. The two reaches that were restored (WC01, WC02) have stable, vegetated banks in each Post-Restoration survey and improved floodplain access in some areas, but are still somewhat entrenched in others. In both of these restored reaches, surveyed cross-sections exhibited aggradation in the three years following completion of restoration. These streams may continue to adjust in the coming years, especially during high flow events. Future Post-Restoration monitoring will enable assessment of their stability and the effects of the restoration activities that occurred.

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6.0 REFERENCES

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APPENDIX A

PHOTOS

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WC01 – Facing downstream at Station 4+50

WC01 - Facing downstream at Station 3+00

WC01 – Facing downstream at Station 2+00

WC01 – Facing downstream at Station 1+00

WC01 – Facing upstream from Station 0+00

WC02 – Facing upstream at Station 3+00

WC02 – Facing upstream at Station 2+00

WC02 – Facing upstream at Station 1+00

WC02 – Facing upstream at Station 0+50

WC02 – Facing upstream at Station 0+00

WC03 – Facing downstream at Station 3+08

WC03 – Facing downstream at Station 2+50

WC03 – Facing downstream at Station 1+50

WC03 – Facing downstream at Station 0+50

WC03 – Facing upstream at Station 0+00

WC04 – Facing downstream at Station 3+00

WC04 – Facing upstream at Station 2+00

WC04 – Facing upstream at Station 1+00

WC04 – Facing upstream at Station 0+50

WC04 – Facing upstream at Station 0+00

WC01 – XS-1 facing upstream

WC01 – XS-1 facing downstream

WC01 – XS-1 facing right bank

WC01 – XS-1 facing left bank

WC01 – XS-2 facing upstream

WC01 – XS-2 facing downstream

WC01 – XS-2 facing right bank

WC01 – XS-2 facing left bank

WC02 – XS-1 facing upstream

WC02 – XS-1 facing downstream

WC02 – XS-1 facing right bank

WC02 – XS-1 facing left bank

WC02 – XS-2 facing upstream

WC02 – XS-2 facing downstream

WC02 – XS-2 facing right bank

WC02 – XS-2 facing left bank


WC03 – XS-1 facing upstream


WC03 – XS-1 facing downstream


WC03 – XS-1 facing right bank


WC03 – XS-1 facing left bank

WC03 – XS-2 facing upstream

WC03 – XS-2 facing downstream

WC03 – XS-2 facing right bank

WC03 – XS-2 facing left bank


WC04 – XS-1 facing upstream


WC04 – XS-1 facing downstream


WC04 – XS-1 facing right bank


WC04 – XS-1 facing left bank

WC04 – XS-2 facing upstream

WC04 – XS-2 facing downstream

WC04– XS-2 facing right bank

WC04 – XS-2 facing left bank

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APPENDIX B

GEOMORPHIC ASSESSMENT DATA

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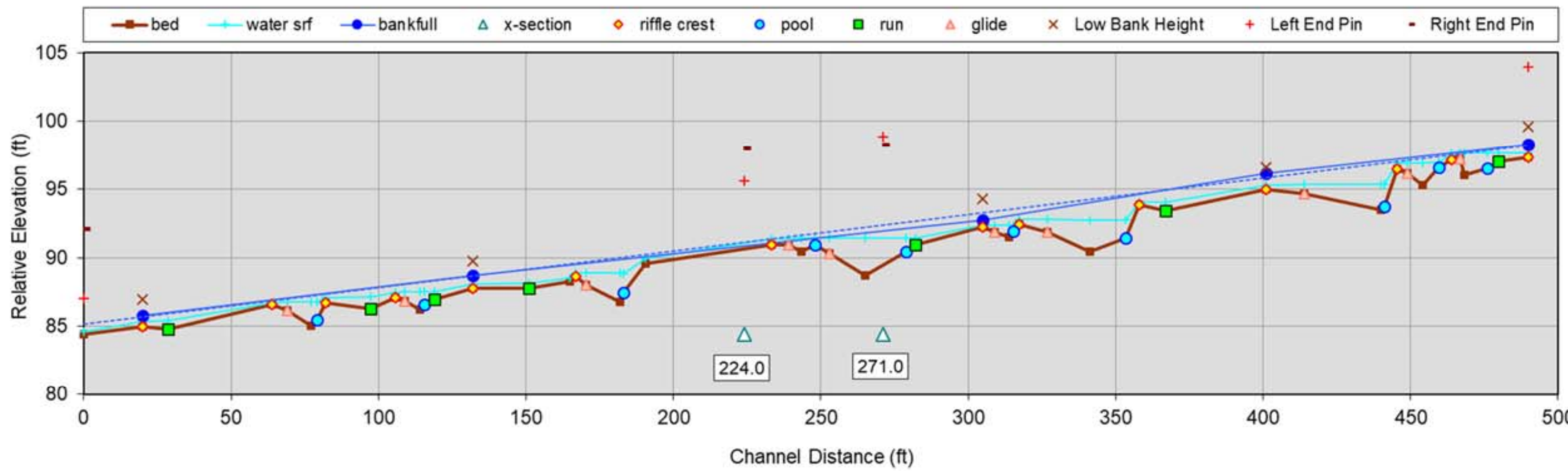
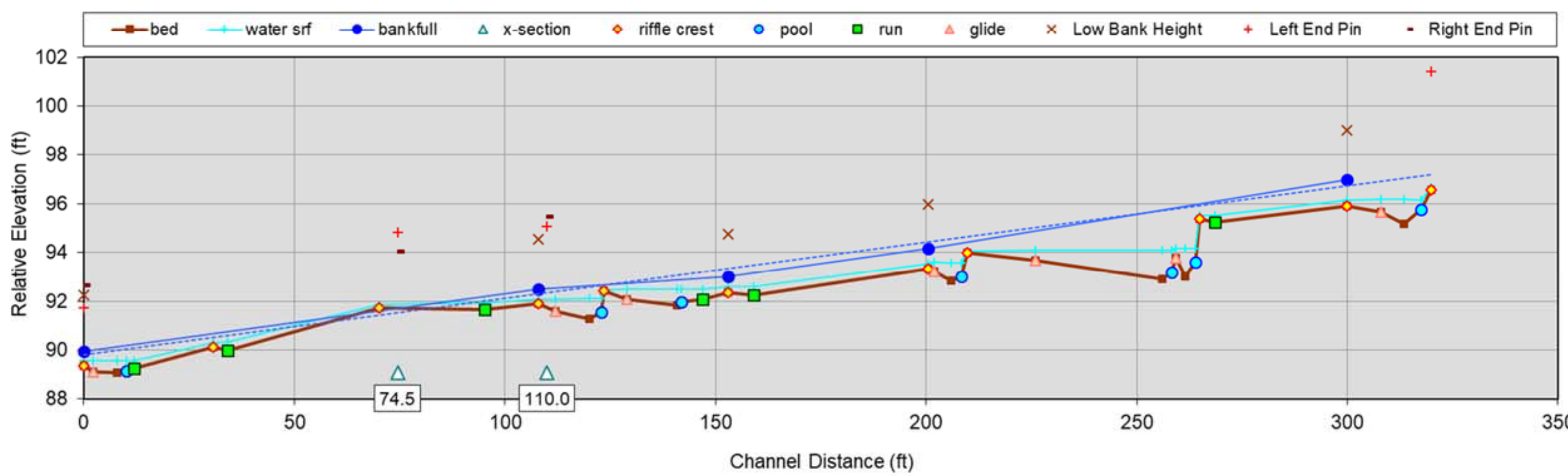
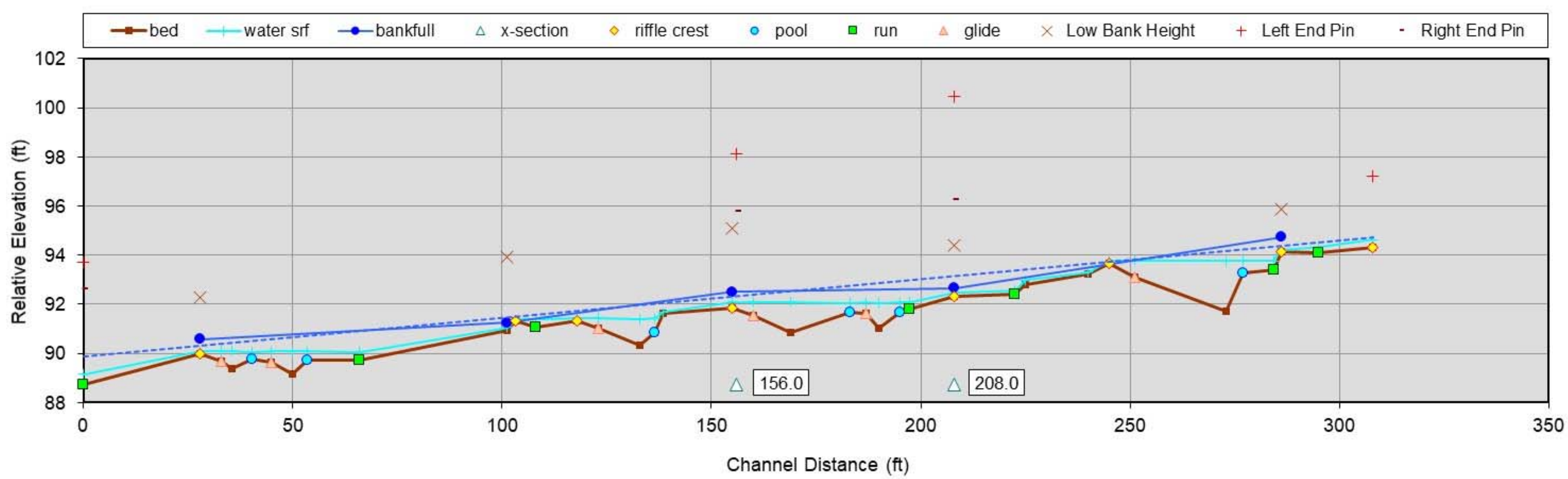
Wheel Creek WC01 2019



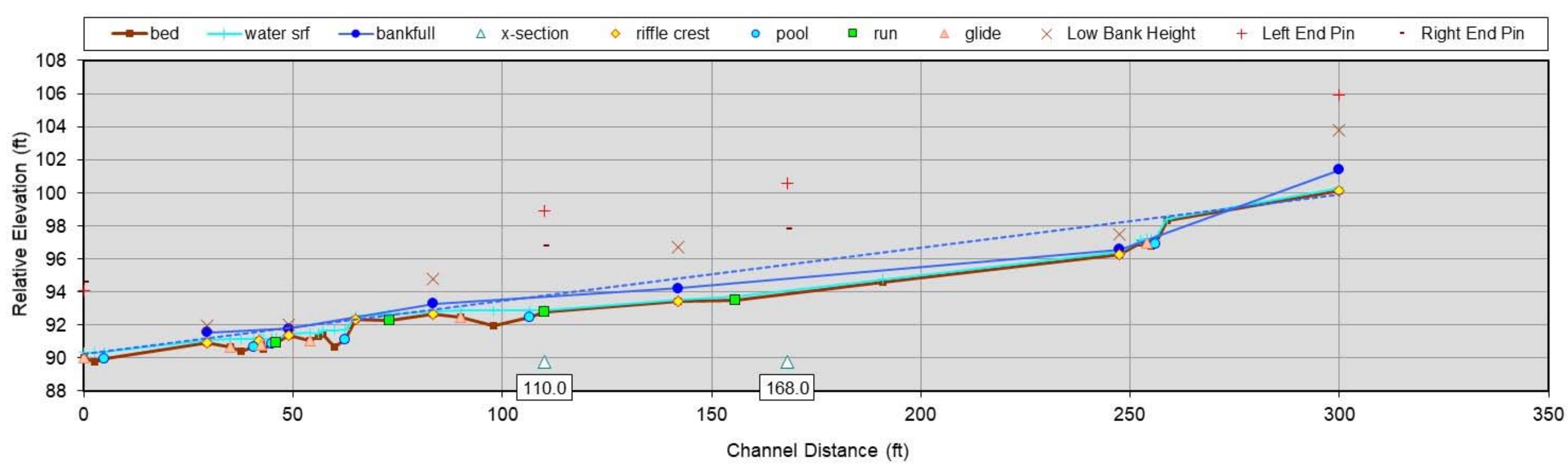
Wheel Creek WC02 2019

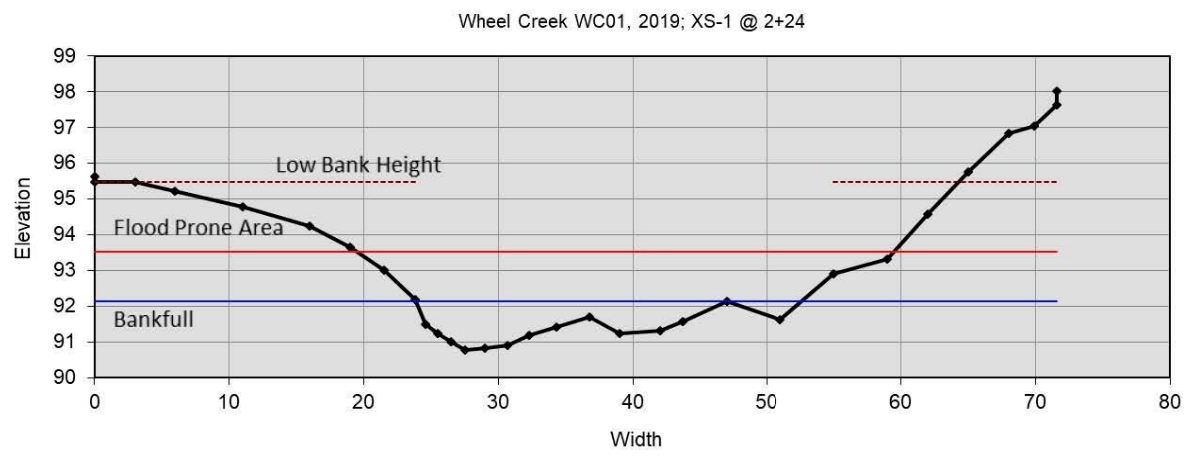


Wheel Creek WC03 2019

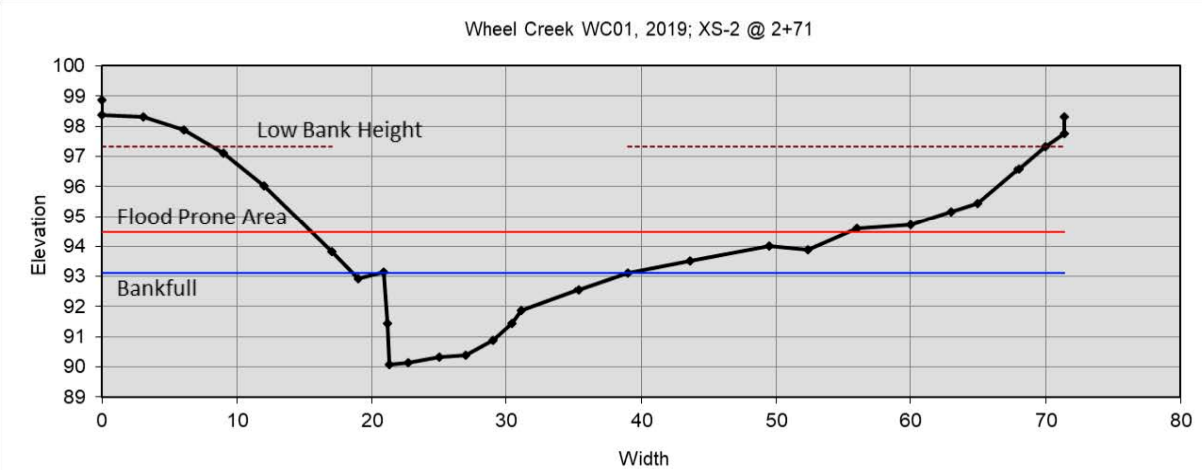


Wheel Creek WC04 2019

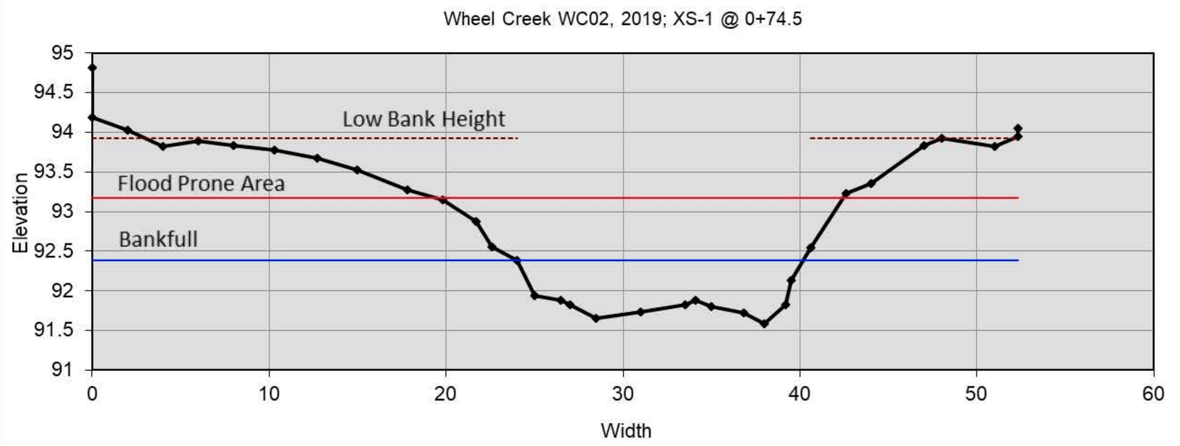




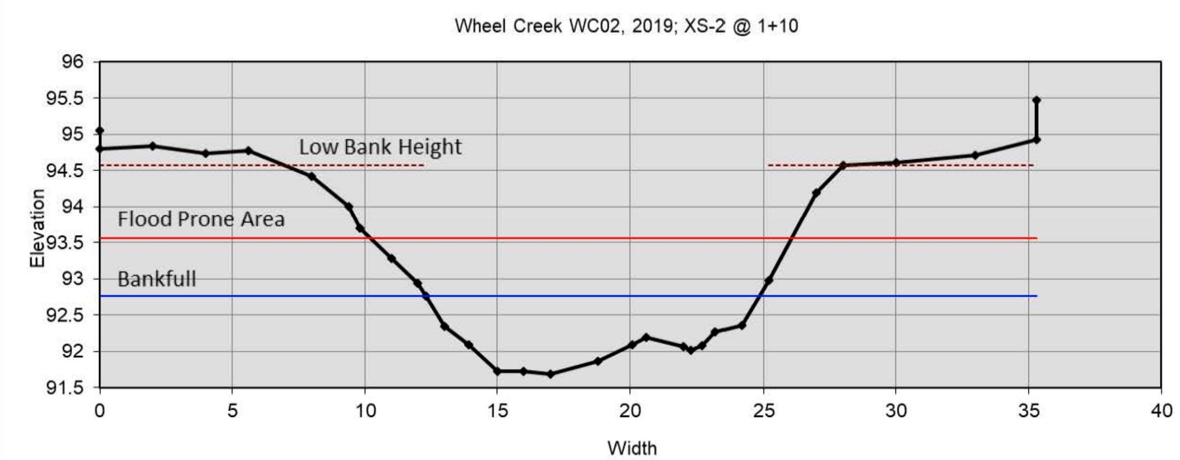
Bankfull Dimensions		Flood Dimensions		Materials	
20.1	x-section area (ft.sq.)	39.9	W flood prone area (ft)	47	D50 Riffle (mm)
28.8	width (ft)	1.4	entrenchment ratio	110	D84 Riffle (mm)
0.7	mean depth (ft)	4.7	low bank height (ft)	34	threshold grain size (mm):
1.4	max depth (ft)	3.4	low bank height ratio		
29.4	wetted parimeter (ft)				
0.7	hyd radi (ft)				
41.2	width-depth ratio				



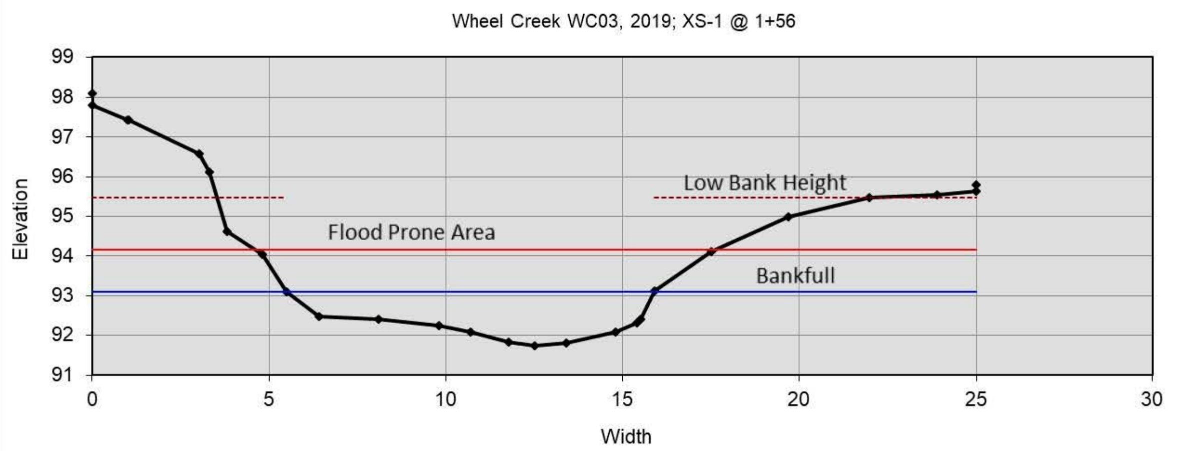
Bankfull Dimensions		Flood Dimensions		Materials	
30.6	x-section area (ft.sq.)	40.0	W flood prone area (ft)	47	D50 Riffle (mm)
20.3	width (ft)	2.0	entrenchment ratio	110	D84 Riffle (mm)
1.5	mean depth (ft)	7.2	low bank height (ft)	56	threshold grain size (mm):
3.1	max depth (ft)	2.4	low bank height ratio		
23.5	wetted parimeter (ft)				
1.3	hyd radi (ft)				
13.5	width-depth ratio				



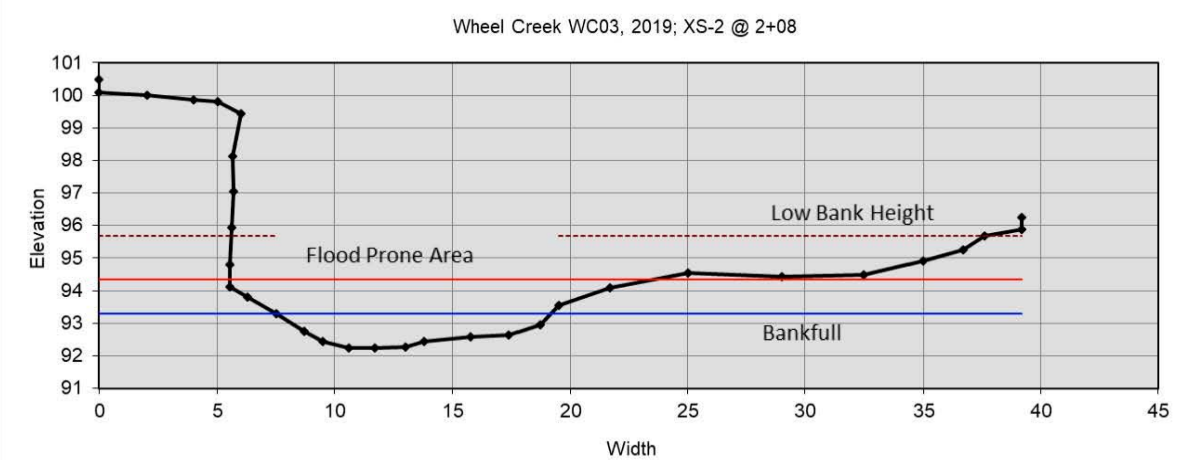
Bankfull Dimensions		Flood Dimensions		Materials	
9.2	x-section area (ft.sq.)	23.0	W flood prone area (ft)	51	D50 Riffle (mm)
16.2	width (ft)	1.4	entrenchment ratio	110	D84 Riffle (mm)
0.6	mean depth (ft)	2.3	low bank height (ft)	39	threshold grain size (mm):
0.8	max depth (ft)	2.9	low bank height ratio		
16.5	wetted parimeter (ft)				
0.6	hyd radi (ft)				
28.5	width-depth ratio				



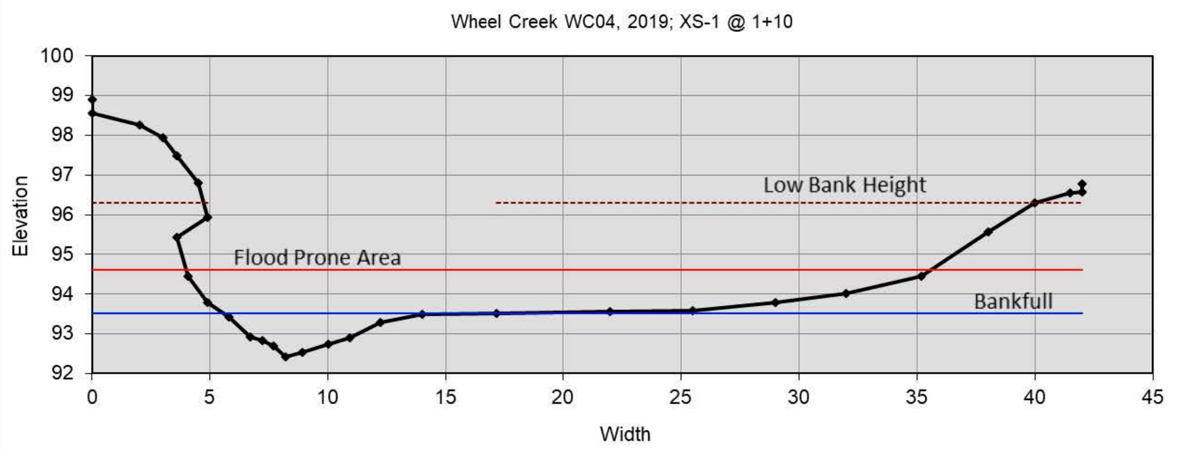
Bankfull Dimensions		Flood Dimensions		Materials	
9.1	x-section area (ft.sq.)	15.9	W flood prone area (ft)	51	D50 Riffle (mm)
12.6	width (ft)	1.3	entrenchment ratio	110	D84 Riffle (mm)
0.7	mean depth (ft)	2.9	low bank height (ft)	18	threshold grain size (mm):
1.1	max depth (ft)	2.7	low bank height ratio		
13.0	wetted parimeter (ft)				
0.7	hyd radi (ft)				
17.4	width-depth ratio				



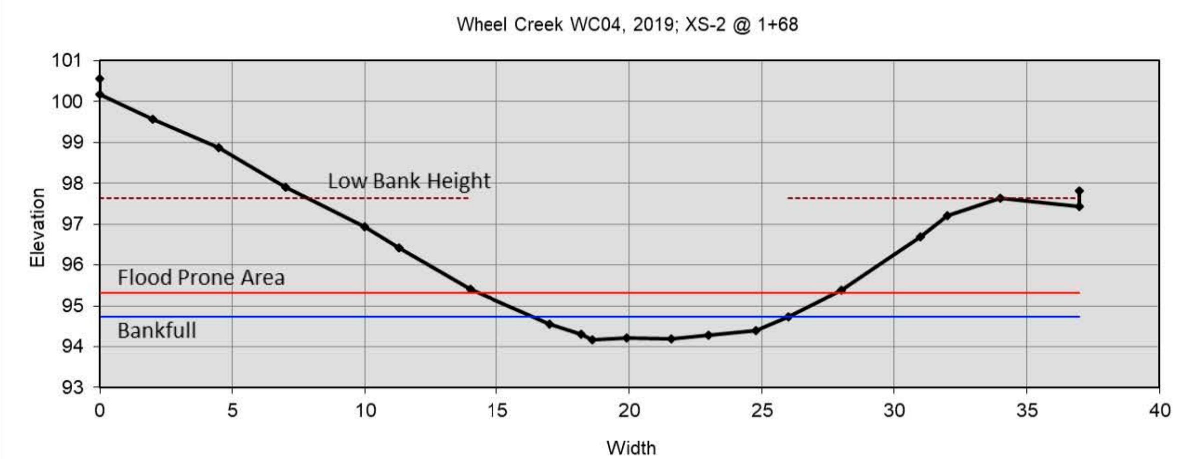
Bankfull Dimensions		Flood Dimensions		Materials	
9.2	x-section area (ft.sq.)	13.0	W flood prone area (ft)	45	D50 Bed (mm)
10.4	width (ft)	1.3	entrenchment ratio	88	D84 Bed (mm)
0.9	mean depth (ft)	3.8	low bank height (ft)	30	threshold grain size (mm):
1.4	max depth (ft)	2.8	low bank height ratio		
11.1	wetted parimeter (ft)				
0.8	hyd radi (ft)				
11.7	width-depth ratio				



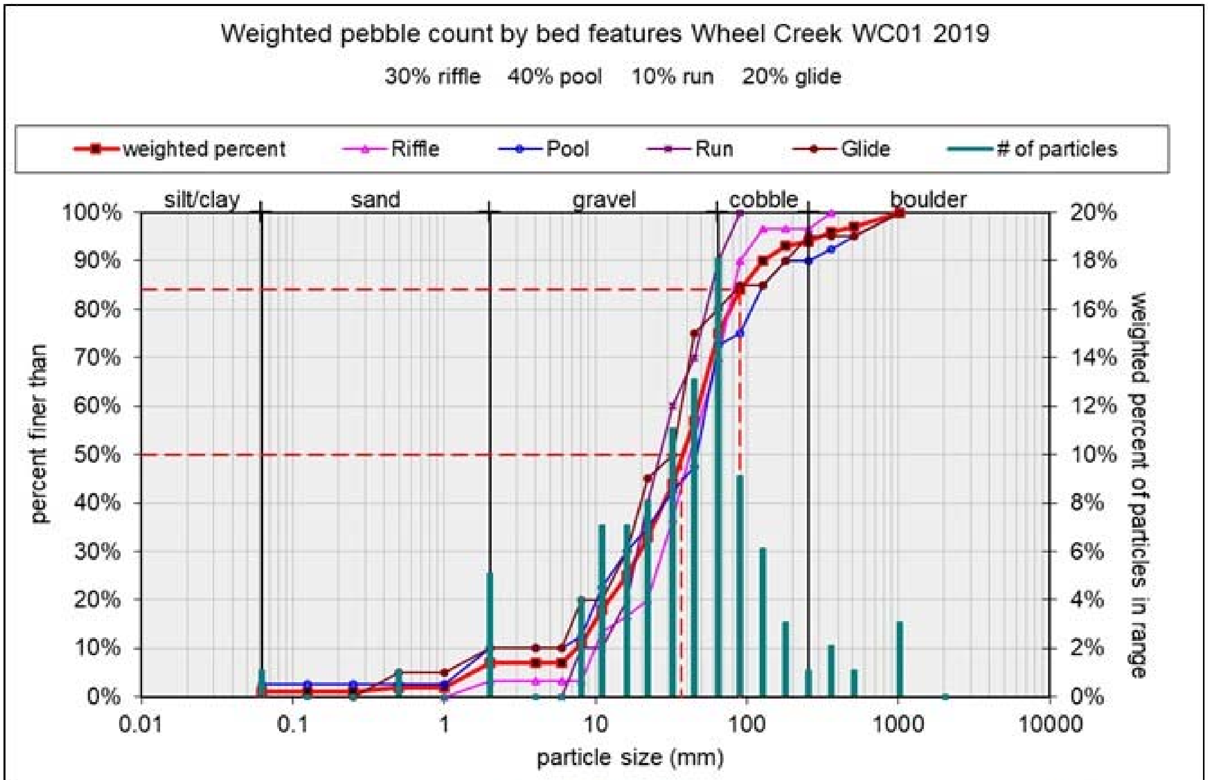
Bankfull Dimensions		Flood Dimensions		Materials	
8.5	x-section area (ft.sq.)	18.1	W flood prone area (ft)	45	D50 Bed (mm)
11.6	width (ft)	1.6	entrenchment ratio	88	D84 Bed (mm)
0.7	mean depth (ft)	3.5	low bank height (ft)	41	threshold grain size (mm):
1.1	max depth (ft)	3.3	low bank height ratio		
12.0	wetted parimeter (ft)				
0.7	hyd radi (ft)				
15.9	width-depth ratio				



Bankfull Dimensions		Flood Dimensions		Materials	
4.7	x-section area (ft.sq.)	31.7	W flood prone area (ft)	1.2	D50 Bed (mm)
11.6	width (ft)	2.7	entrenchment ratio	29	D84 Bed (mm)
0.4	mean depth (ft)	3.9	low bank height (ft)	26	threshold grain size (mm):
1.1	max depth (ft)	3.5	low bank height ratio		
12.0	wetted parimeter (ft)				
0.4	hyd radi (ft)				
28.8	width-depth ratio				



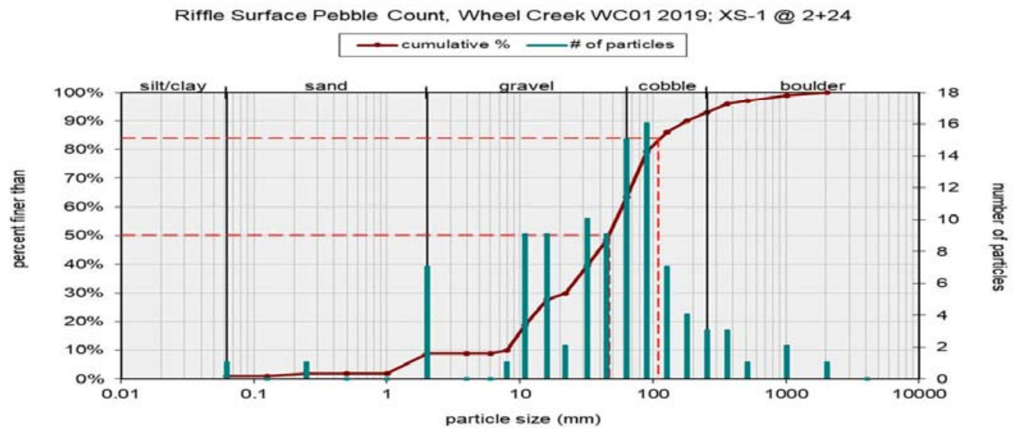
Bankfull Dimensions		Flood Dimensions		Materials	
3.9	x-section area (ft.sq.)	13.5	W flood prone area (ft)	1.2	D50 Bed (mm)
9.7	width (ft)	1.4	entrenchment ratio	29	D84 Bed (mm)
0.4	mean depth (ft)	3.5	low bank height (ft)	33	threshold grain size (mm):
0.6	max depth (ft)	6.0	low bank height ratio		
9.8	wetted parimeter (ft)				
0.4	hyd radi (ft)				
24.1	width-depth ratio				



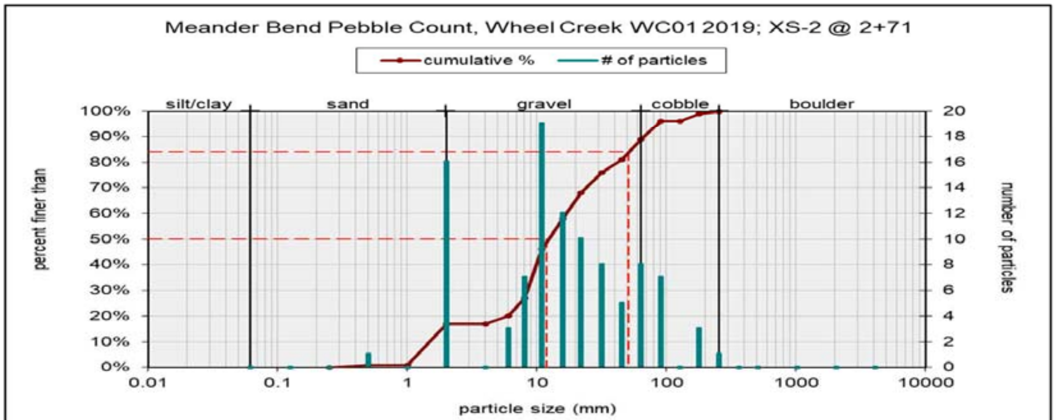
Size (mm)	
D16	10
D35	24
D50	37
D65	53
D84	90
D95	300

Size Distribution	
mean	30.0
dispersion	3.1
skewness	-0.09

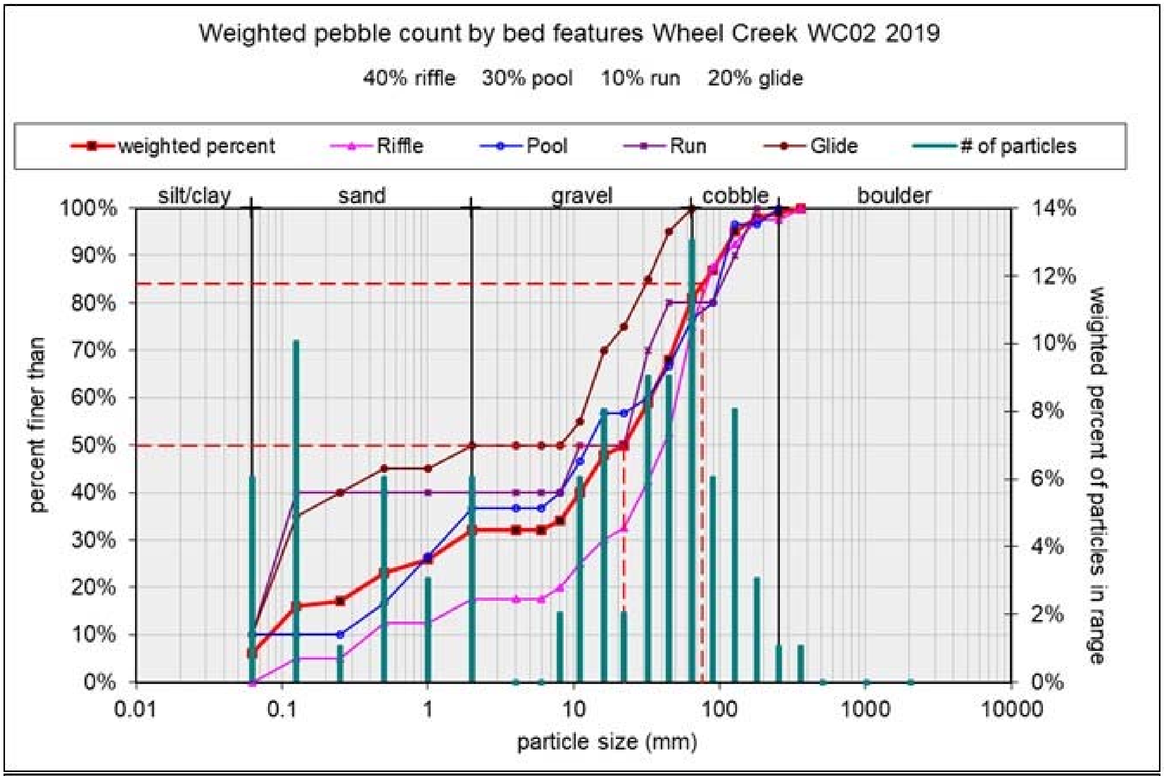
Type	
silt/clay	1%
sand	6%
gravel	68%
cobble	19%
boulder	6%



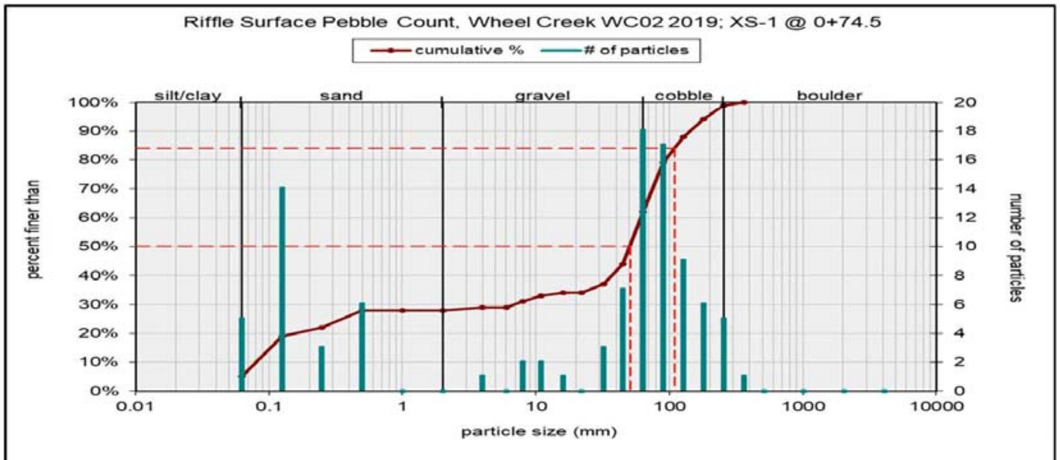
Size (mm)		Size Distribution		Type	
D16	9.9	mean	33.0	silt/clay	1%
D35	27	dispersion	3.5	sand	8%
D50	47	skewness	-0.15	gravel	54%
D65	66			cobble	30%
D84	110			boulder	7%
D95	320				



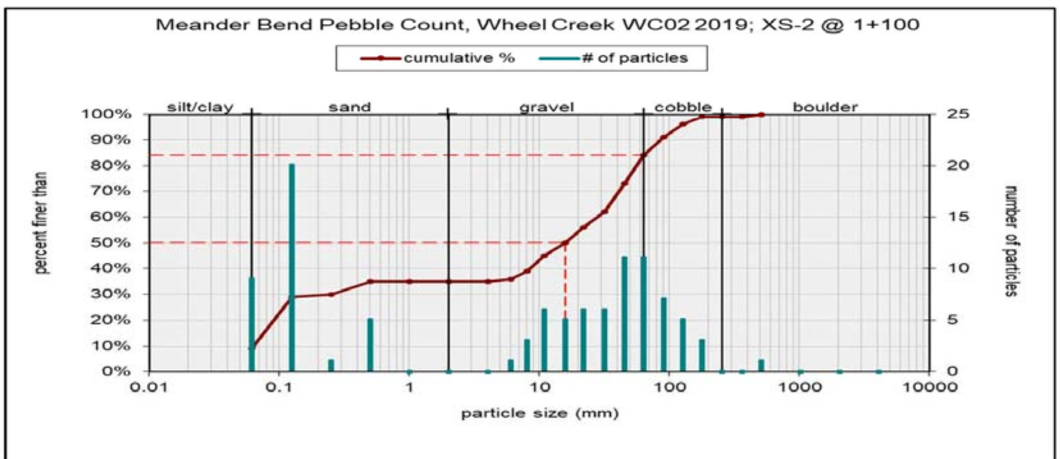
Size (mm)			Size Distribution		Type	
D16	1.9	3.4	mean	9.8	silt/clay	0%
D35	9.1	12	dispersion	5.3	sand	17%
D50	12	17	skewness	-0.07	gravel	72%
D65	20	20			cobble	11%
D84	51	29			boulder	0%
D95	86	39				



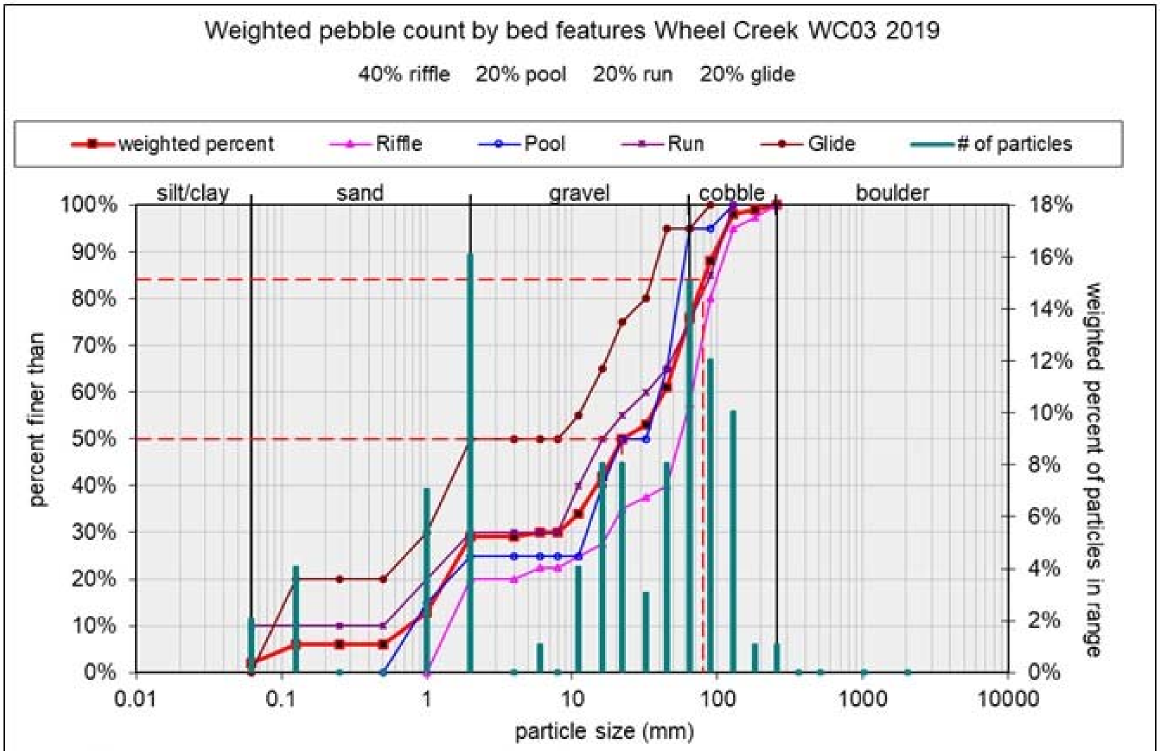
Size (mm)		Size Distribution		Type	
D16	0.13	mean	3.1	silt/clay	6%
D35	8.4	dispersion	86.3	sand	26%
D50	22	skewness	-0.51	gravel	49%
D65	40			cobble	18%
D84	76			boulder	1%
D95	130				



Size (mm)		Size Distribution		Type	
D16	0.11	mean	3.5	silt/clay	5%
D35	25	dispersion	232.9	sand	23%
D50	51	skewness	-0.67	gravel	34%
D65	68			cobble	37%
D84	110			boulder	1%
D95	190				



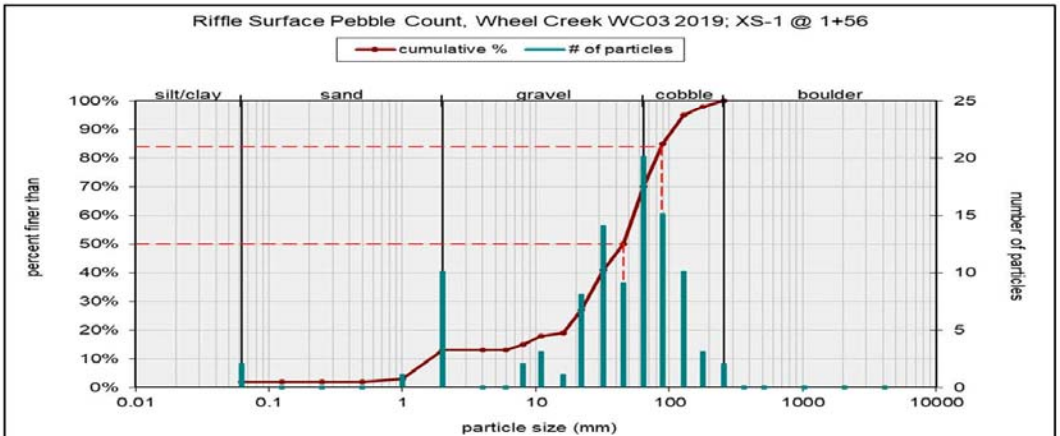
Size (mm)			Size Distribution		Type	
D16	0.079	3.4	mean	2.2	silt/clay	9%
D35	0.5	12	dispersion	103.3	sand	26%
D50	16	17	skewness	-0.50	gravel	49%
D65	35	20			cobble	15%
D84	64	29			boulder	1%
D95	120	39				



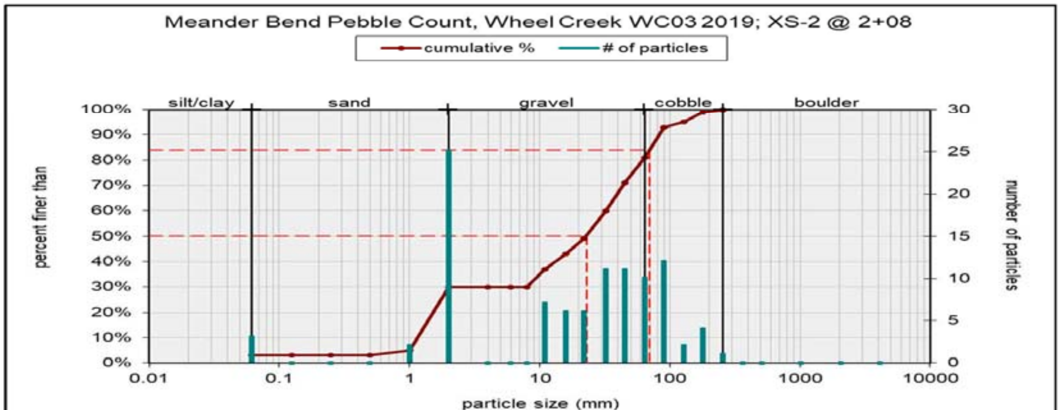
Size (mm)	
D16	1.1
D35	12
D50	22
D65	49
D84	80
D95	120

Size Distribution	
mean	9.4
dispersion	11.8
skewness	-0.27

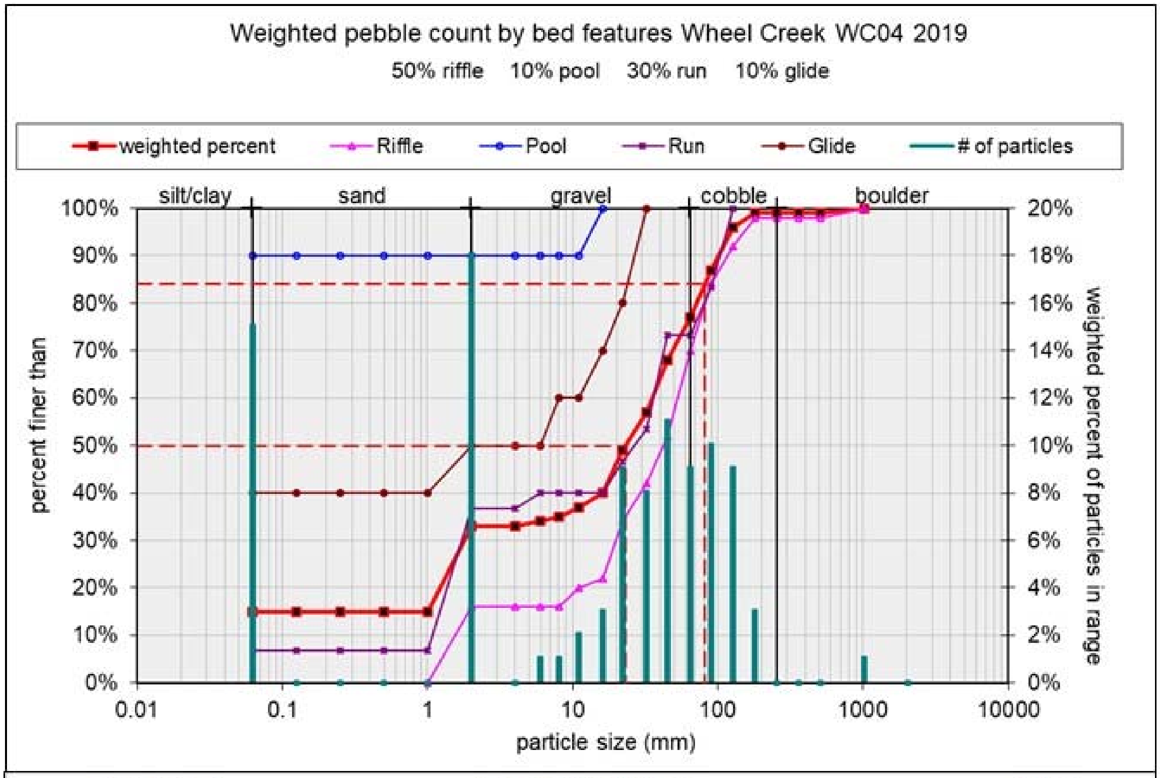
Type	
silt/clay	2%
sand	27%
gravel	47%
cobble	24%
boulder	0%



Size (mm)		Size Distribution		Type	
D16	8.9	mean	28.0	silt/clay	2%
D35	27	dispersion	3.5	sand	11%
D50	45	skewness	-0.21	gravel	57%
D65	59			cobble	30%
D84	88			boulder	0%
D95	130				



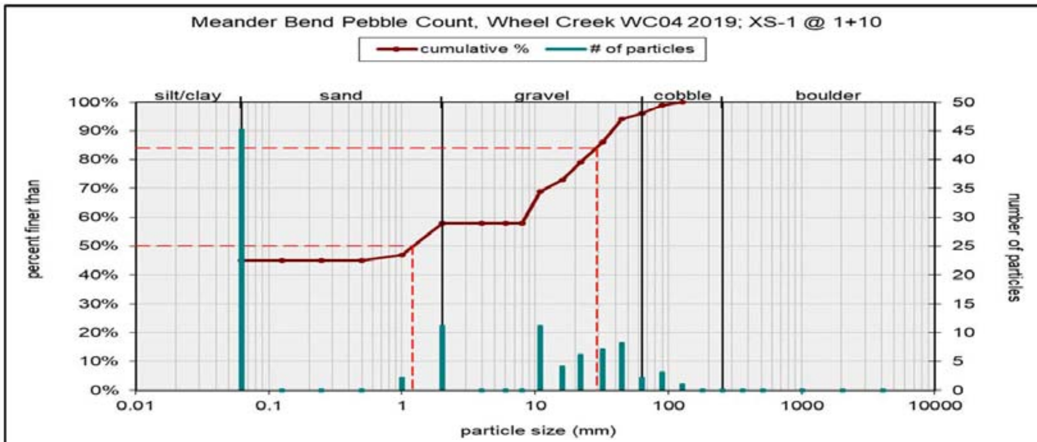
Size (mm)			Size Distribution		Type	
D16	1.4	3.4	mean	9.9	silt/clay	3%
D35	10	12	dispersion	9.7	sand	27%
D50	23	17	skewness	-0.28	gravel	51%
D65	37	20			cobble	19%
D84	70	29			boulder	0%
D95	130	39				



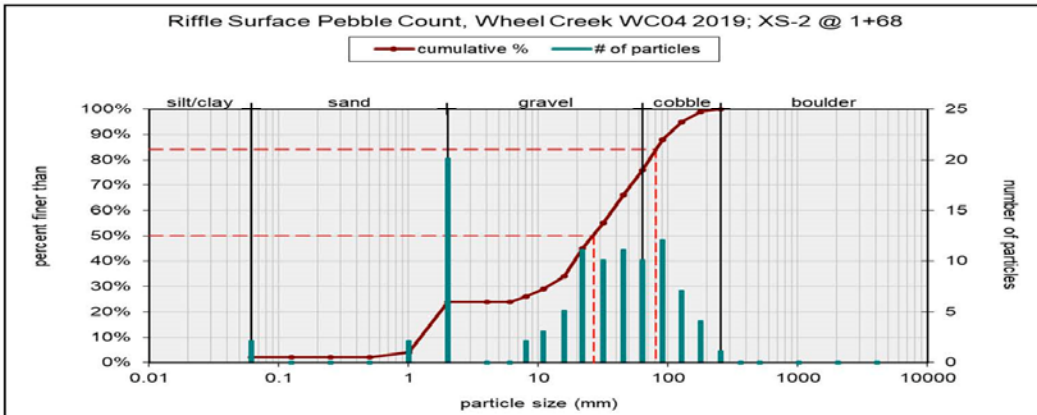
Size (mm)	
D16	1
D35	8
D50	23
D65	41
D84	81
D95	120

Size Distribution	
mean	9.0
dispersion	13.3
skewness	-0.29

Type	
silt/clay	15%
sand	18%
gravel	44%
cobble	22%
boulder	1%



Size (mm)		Size Distribution		Type	
D16	0.062	mean	1.3	silt/clay	45%
D35	0.062	dispersion	21.8	sand	13%
D50	1.2	skewness	0.03	gravel	38%
D65	9.8			cobble	4%
D84	29			boulder	0%
D95	54				



Size (mm)			Size Distribution		Type	
D16	1.5	3.4	mean	11.0	silt/clay	2%
D35	16	12	dispersion	10.5	sand	22%
D50	27	17	skewness	-0.30	gravel	52%
D65	44	20			cobble	24%
D84	80	29			boulder	0%
D95	130	39				

APPENDIX C

ANNUAL COMPARISONS

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Table C-1. Comparisons of Longitudinal Profile Survey Pre-Restoration Year 1 – Year 4 (2010-2015) and Post-Restoration Years 1 – 3 (2017-2019)							
Reach	**Year**	**Length (ft)**	**Slope**	**Proportion of Features**			
				Riffle	**Run**	**Pool**	**Glide**
WC01*	2010	400	2.3%	43.6%	11.3%	22.1%	23.0%
	2012	420	2.2%	54.6%	7.3%	29.2%	8.9%
	2013	420	2.2%	55.7%	8.2%	23.8%	12.3%
	2015	420	2.2%	50.9%	24.8%	14.1%	10.2%
	2017	*490*	*2.6%*	*47.5%*	*7.6%*	*36.6%*	*8.3%*
	2018	*490*	*2.7%*	*48.5%*	*8.6%*	*28.6%*	*14.4%*
	2019	*490*	*2.7%*	*46.6%*	*12.7%*	*29.4%*	*11.3%*
WC02*	2010	350	2.3%	53.4%	0%	46.6%	0%
	2012	350	2.4%	33.7%	11.0%	38.6%	16.7%
	2013	350	2.3%	48.1%	12.6%	26.3%	13.0%
	2015	350	2.2%	49.4%	25.1%	13.4%	12.1%
	2017	*321.5*	*2.3%*	*57.3%*	*6.3%*	*28.5%*	*10.5%*
	2018	*320*	*2.3%*	*45.0%*	*15.3%*	*28.1%*	*11.6%*
	2019	*320*	*2.2%*	*47.6%*	*13.9%*	*26.4%*	*12.1%*
WC03	2010	300	1.7%	34.4%	0%	65.6%	0%
	2012	300	1.8%	24.0%	8.5%	54.9%	12.6%
	2013	306.3	1.6%	37.2%	15.9%	30.4%	16.5%
	2015	306	1.7%	32.0%	9.5%	34.0%	24.5%
	2017	*306*	*1.7%*	*52.4%*	*13.6%*	*23.5%*	*10.5%*
	2018	*309*	*1.7%*	*48.4%*	*14.3%*	*29.4%*	*7.8%*
	2019	*308*	*1.8%*	*46.0%*	*16.3%*	*28.1%*	*9.6%*
WC04	2010	300	3.5%	60.0%	0%	40.0%	0%
	2012	300	3.4%	41.3%	16.2%	30.3%	12.2%
	2013	300	3.4%	46.5%	11.0%	27.9%	14.6%
	2015	300	3.4%	50.3%	21.7%	19.0%	9.0%
	2017	*300*	*3.5%*	*48.2%*	*24.3%*	*14.0%*	*13.5%*
	2018	*300*	*3.7%*	*67.5%*	*13.0%*	*13.9%*	*5.2%*
	2019	*300*	*3.3%*	*70.0%*	*8.7%*	*13.3%*	*8.0%*
*Profiles and cross-sections re-established during Post-Restoration Year 1 (2017)							

Table C-2. Comparisons of Cross-sectional Survey Analyses Pre-Restoration Years 1 – 4 (2010 – 2015) and Post-Restoration Years 1 – 3 (2017 – 2019)

Reach	Year	Station	Feature	Bankfull Width (ft)	Mean Depth (ft)	Width/ Depth Ratio	Entrench-ment Ratio	Bankfull Area (ft^2)	Top of Bank Area (ft^2)
WC01*	2010	2+30	Crossover Riffle	21.1	1.0	22.2	1.5	20.1	73.0
	2012	2+30	Crossover Riffle	21.3	1.1	18.6	1.5	24.5	78.1
	2013	2+29	Crossover Riffle	21.6	1.1	20.2	1.5	23.2	66.9
	2015	2+29	Crossover Riffle	21.0	1.0	21.6	1.5	20.5	74.8
	2017	*2+24*	*Crossover Riffle*	*20.7*	*0.8*	*26.8*	*1.7*	*16.0*	*164.4*
	2018	*2+24*	*Crossover Riffle*	*21.7*	*1.0*	*21.9*	*1.8*	*21.6*	*169.6*
	2019	*2+24*	*Crossover Riffle*	*28.8*	*0.7*	*41.2*	*1.4*	*20.1*	*161.7*
	2010	2+95	Meander/Riffle	22.1	0.8	26.0	1.5	18.8	230.1
	2012	2+95	Meander/Riffle	28.9	0.8	37.5	1.5	22.3	246.9
	2013	2+95	Meander/Riffle	29.0	0.9	34.1	1.5	24.7	212.7
	2015	2+95	Meander/Riffle	29.1	1.2	25.0	1.6	33.8	259.6
	2017	*2+71*	*Meander/Pool*	*21.3*	*2.0*	*10.7*	*1.4*	*42.6*	*269.7*
	2018	*2+71*	*Meander/Pool*	*21.5*	*1.5*	*14.5*	*1.8*	*31.8*	*236.4*
	2019	*2+71*	*Meander/Pool*	*20.3*	*1.5*	*13.5*	*2.0*	*30.6*	*223.0*
WC02*	2010	1+37	Crossover Riffle	13.1	0.7	18.4	1.2	9.3	31.6
	2012	1+38	Crossover Riffle	14.3	0.6	24.1	1.2	8.5	37.1
	2013	1+38	Crossover Riffle	14.3	0.7	19.4	1.2	10.6	36.7
	2015	1+38	Crossover Riffle	13.9	0.8	17.9	1.2	10.8	28.4
	2017	*1+10*	*Crossover Riffle*	*11.6*	*0.5*	*24.6*	*1.3*	*5.5*	*38.6*
	2018	*1+10*	*Crossover Riffle*	*13.6*	*0.7*	*20.8*	*1.4*	*8.9*	*56.5*
	2019	*1+10*	*Pool*	*12.6*	*0.7*	*17.4*	*1.3*	*9.1*	*38.4*
	2010	3+24	Meander/Riffle	16.7	0.9	19.3	1.3	14.5	70.3
	2012	3+24	Meander/Riffle	14.6	0.6	23.8	1.4	9.0	71.7
	2013	3+25.5	Meander/Riffle	15.6	0.7	21.8	1.5	11.1	72.0
	2015	3+24	Meander/Riffle	16.4	0.9	19.1	1.4	14.0	74.6
	2017	*0+74.5*	*Pool*	*13.6*	*1.3*	*10.2*	*1.3*	*18.2*	*49.0*
	2018	*0+74.5*	*Pool*	*11.6*	*0.7*	*16.5*	*1.4*	*8.1*	*43.5*
	2019	*0+74.5*	*Crossover Riffle*	*16.2*	*0.6*	*28.5*	*1.4*	*9.2*	*48.4*
WC03	2010	1+55	Crossover Riffle	9.2	0.4	24.1	1.1	3.5	37.5
	2012	1+57	Pool	10.6	1.1	9.8	1.3	11.4	41.3
	2013	1+56	Crossover Riffle	10.1	0.9	11.8	1.2	8.6	38.2
	2015	1+55	Crossover Riffle	9.3	0.7	12.7	1.2	6.8	37.9
	2017	*1+56*	*Crossover Riffle*	*7.3*	*0.9*	*8.6*	*1.7*	*7.3*	*35.0*
	2018	*1+56*	*Crossover Riffle*	*10.0*	*1.1*	*9.4*	*1.3*	*10.7*	*41.6*
	2019	*1+56*	*Crossover Riffle*	*10.4*	*0.9*	*11.7*	*1.3*	*9.2*	*42.3*
	2010	2+07	Meander/Pool	7.2	0.5	13.0	1.9	3.9	43.8
	2012	2+08	Meander/Pool	10.2	1.2	8.4	2.5	12.5	56.2
	2013	2+12	Meander/Pool	9.7	1.0	10.0	2.7	9.4	55.0
	2015	2+07	Meander/Pool	9.9	1.1	9.4	2.8	10.5	61.4
	2017	*2+08*	*Meander/Run*	*9.8*	*0.9*	*12.2*	*2.7*	*9.8*	*61.5*
	2018	*2+08*	*Meander/Run*	*11.5*	*0.6*	*18.3*	*2.3*	*7.2*	*61.8*
	2019	*2+08*	*Meander/Run*	*11.6*	*0.7*	*15.9*	*1.6*	*8.5*	*62.6*
WC04	2010	1+08	Meander/Riffle	4.3	0.4	9.8	4.3	1.9	92.5
	2012	1+08	Meander/Pool	6.7	0.6	11.4	3.9	4.0	95.9
	2013	1+08	Meander/Pool	13.0	0.6	23.5	2.2	7.2	99.9
	2015	1+08	Meander/Pool	13.6	0.6	24.0	2.3	7.7	102.8

Table C-2. (Continued)									
Reach	**Year**	**Station**	**Feature**	**Bankfull Width (ft)**	**Mean Depth (ft)**	**Width/ Depth Ratio**	**Entrench-ment Ratio**	**Bankfull Area (ft^2)**	**Top of Bank Area (ft^2)**
WC04	*2017*	*1+10*	*Meander/Pool*	*20.6*	*0.4*	*51.3*	*1.5*	*8.3*	*99.8*
	2018	*1+10*	*Meander/Pool*	*6.8*	*0.6*	*13.6*	*3.4*	*4.5*	*93.4*
	2019	*1+10*	*Meander/Pool*	*11.6*	*0.4*	*28.8*	*2.7*	*4.7*	*90.7*
	2010	1+68	Crossover Riffle	8.9	0.4	24.0	1.4	3.3	55.9
	2012	1+68	Crossover Riffle	9.2	0.5	18.9	1.5	4.4	57.8
	2013	1+68	Crossover Riffle	10.4	0.5	20.4	1.4	5.3	56.3
	2015	1+68	Crossover Riffle	11.1	0.6	17.4	1.6	7.1	55.6
	2017	*1+68*	*Crossover Riffle*	*10.4*	*0.5*	*22.3*	*1.4*	*4.8*	*54.8*
	2018	*1+68*	*Crossover Riffle*	*9.2*	*0.3*	*28.8*	*1.3*	*3.0*	*55.4*
	2019	*1+68*	*Crossover Riffle*	*9.7*	*0.4*	*24.1*	*1.4*	*3.9*	*56.0*
*Profiles and cross-sections re-established during Post-Restoration Year 1 (2017)									

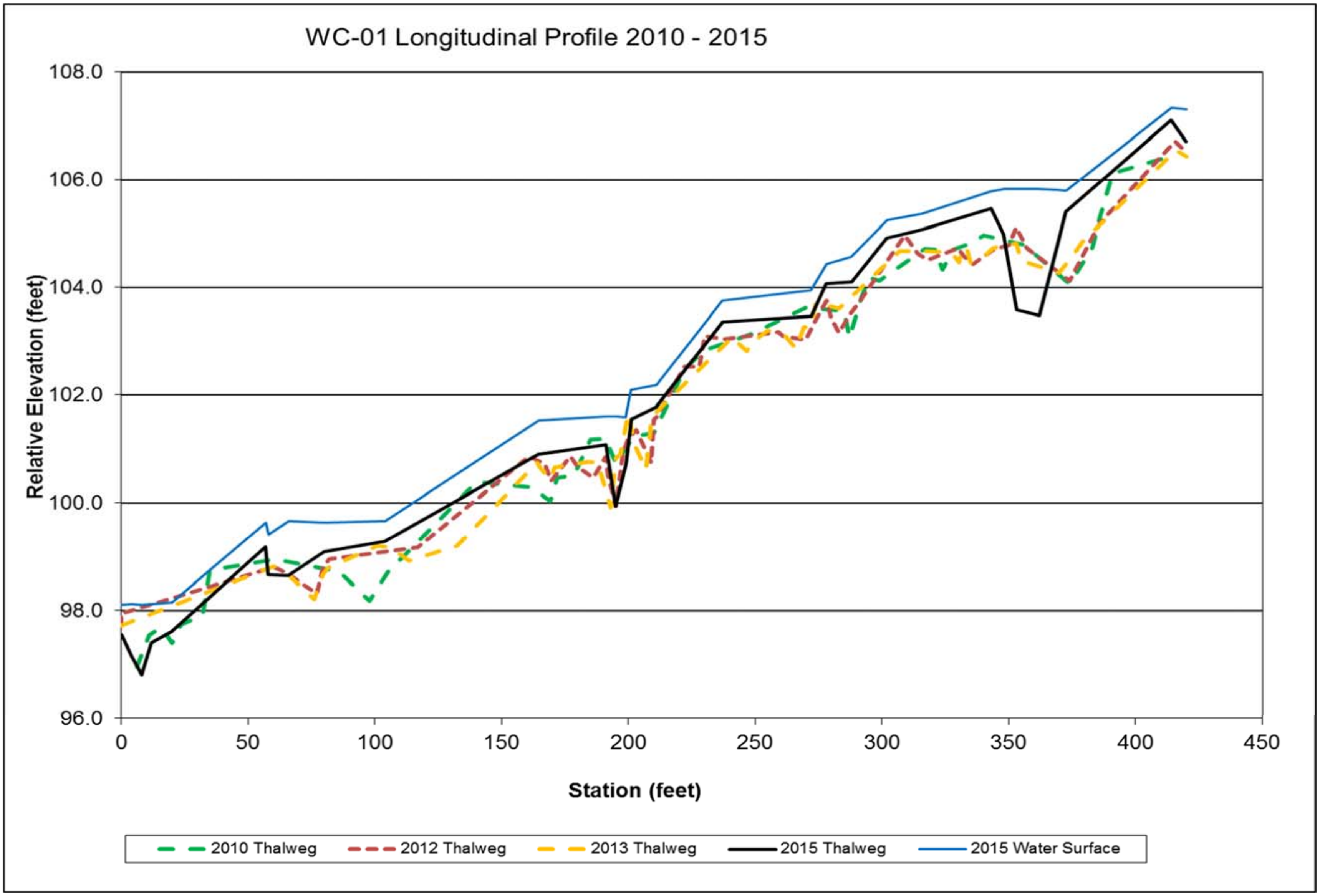

Figure C-1. WC-01 Longitudinal Profile (Pre-Restoration)

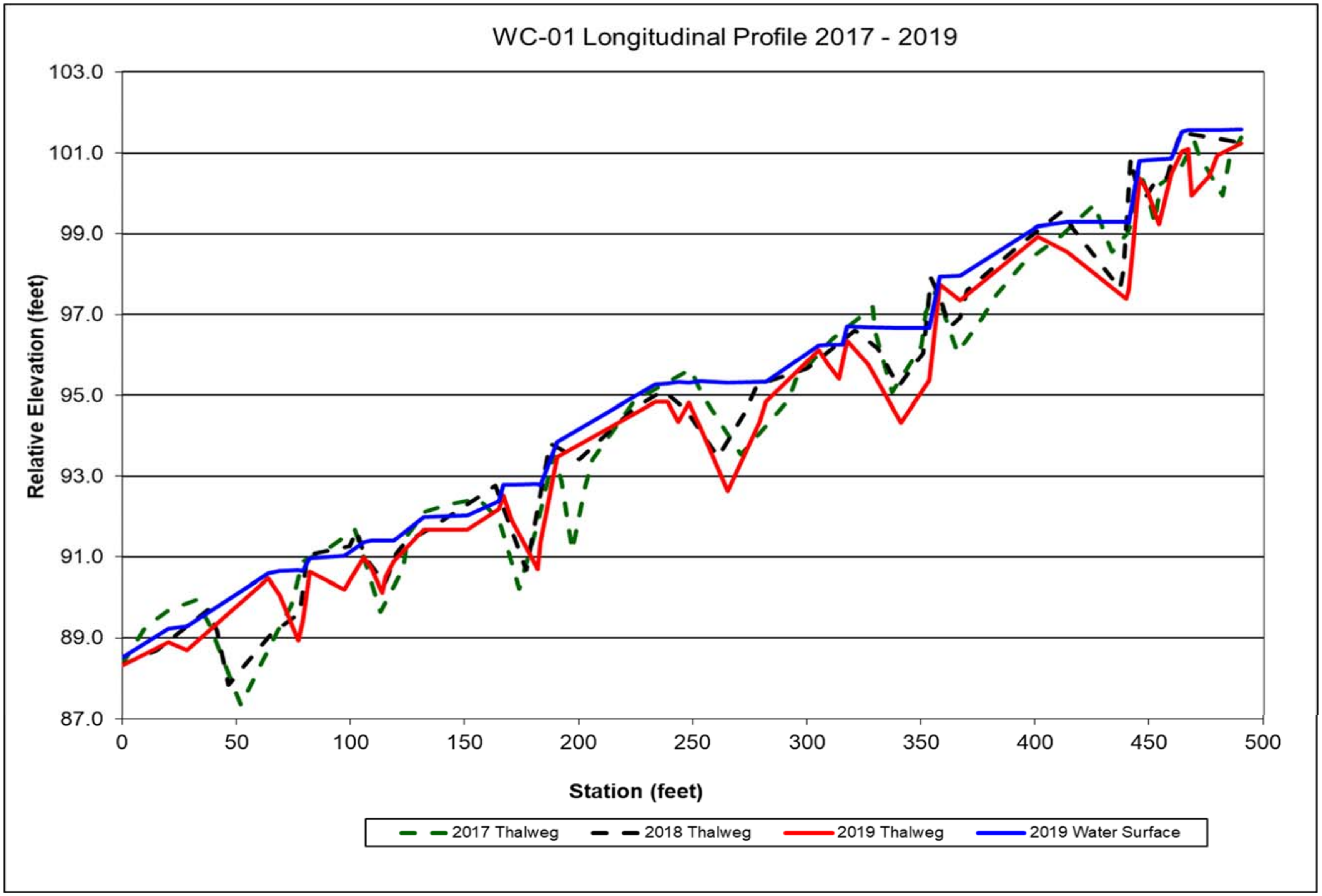

Figure C-2. WC-01 Longitudinal Profile (Post-Restoration)

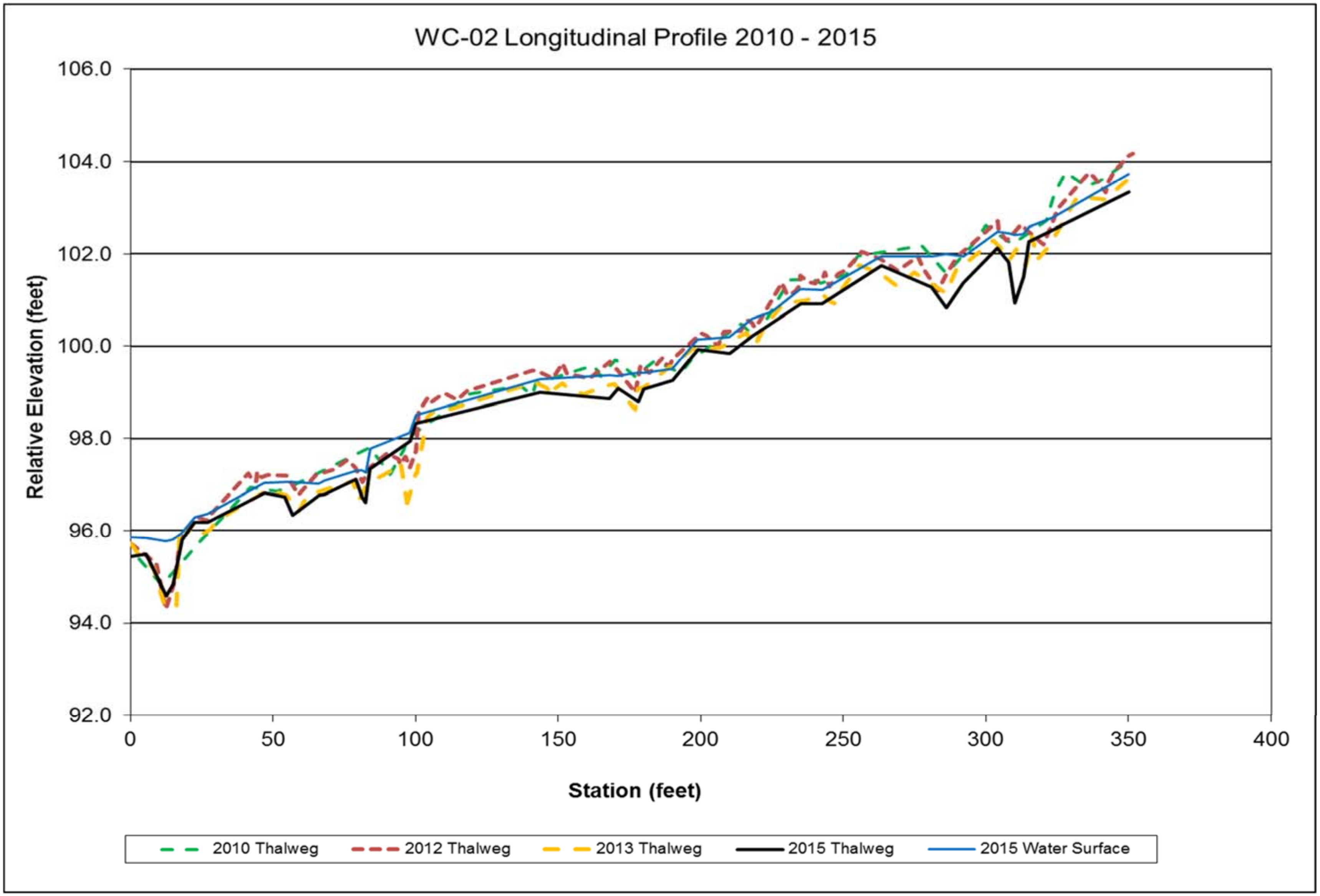

Figure C-3. WC-02 Longitudinal Profile (Pre-Restoration)

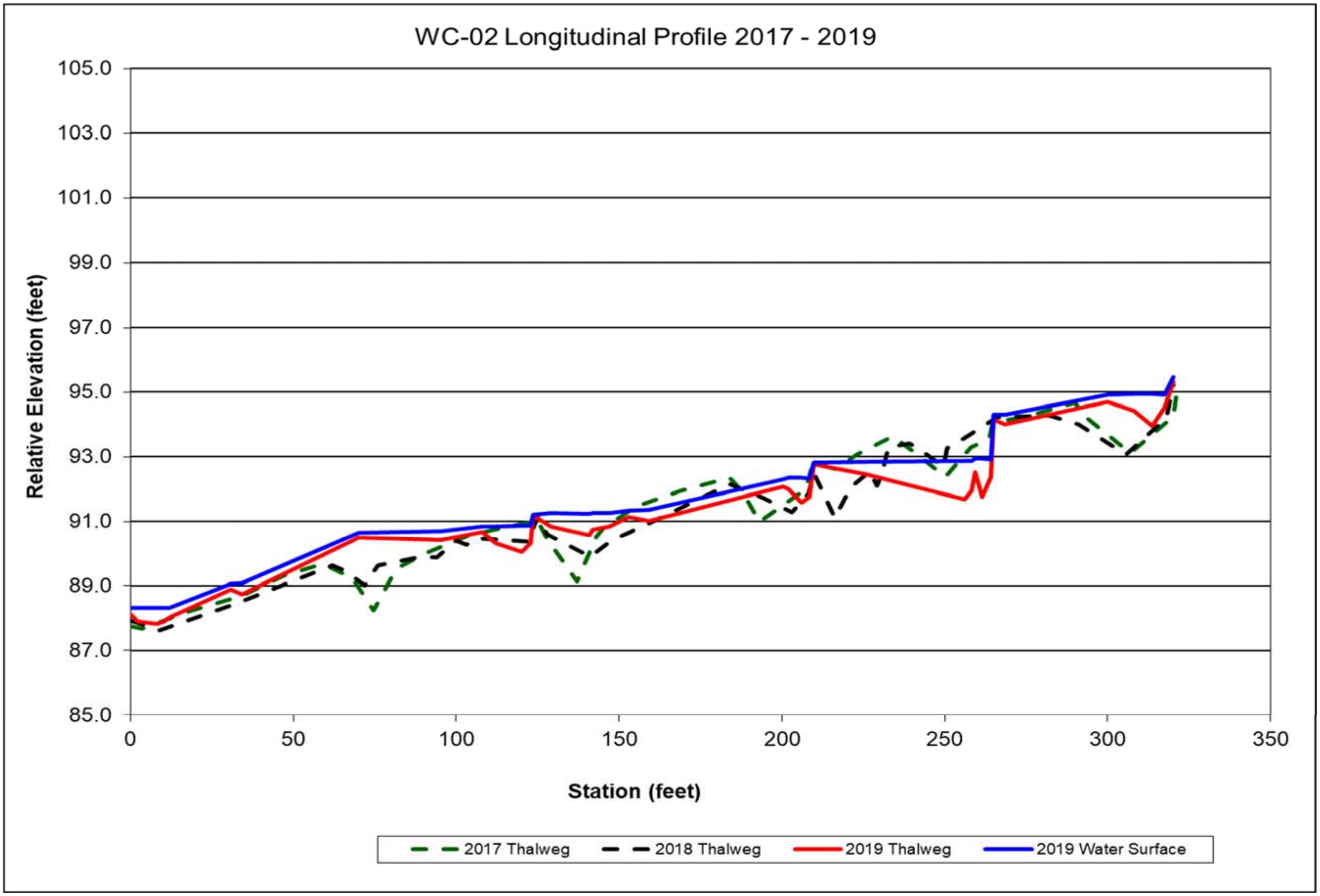

Figure C-4. WC-02 Longitudinal Profile (Post-Restoration)

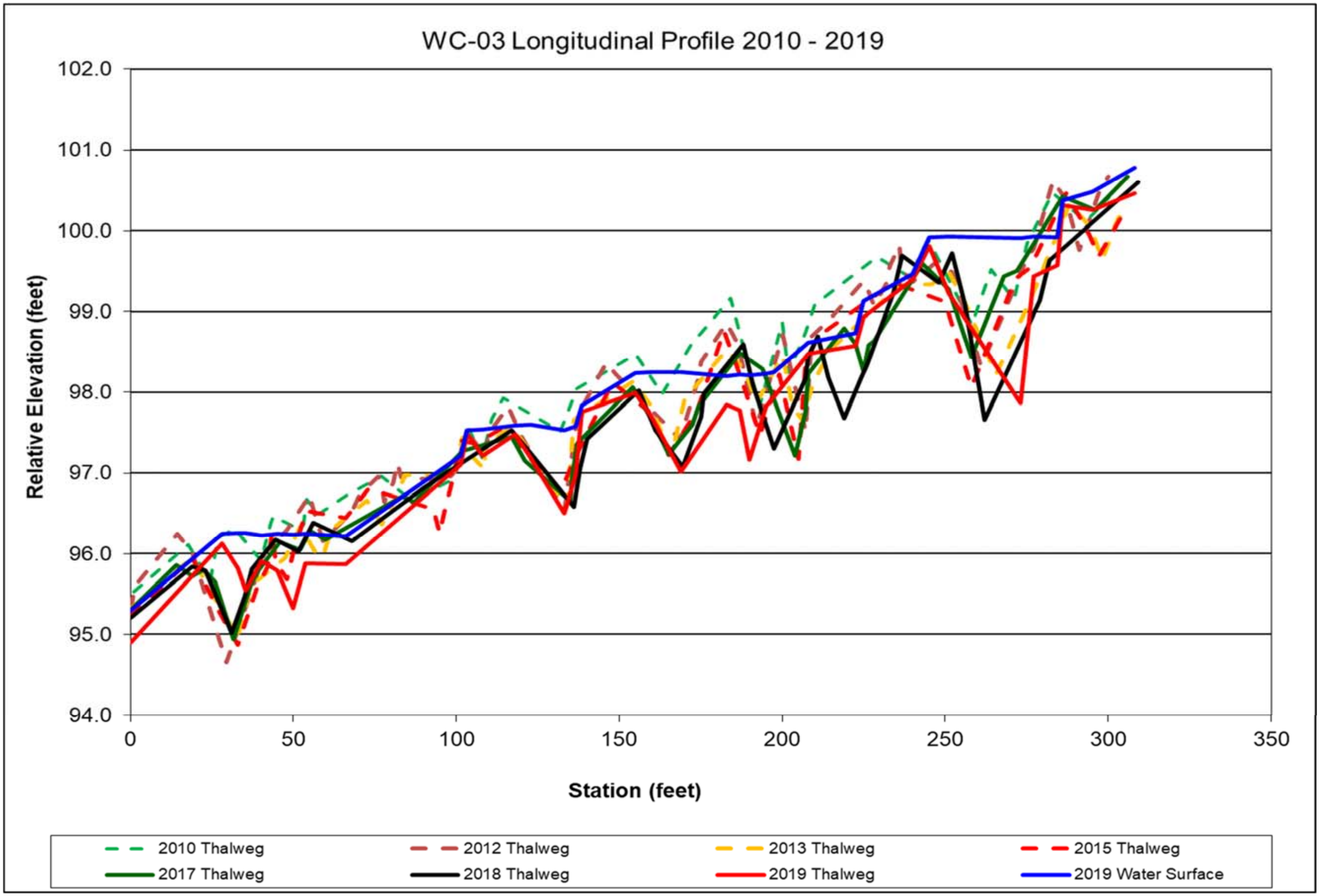

Figure C-5. WC-03 Longitudinal Profile (Pre- and Post-Restoration)

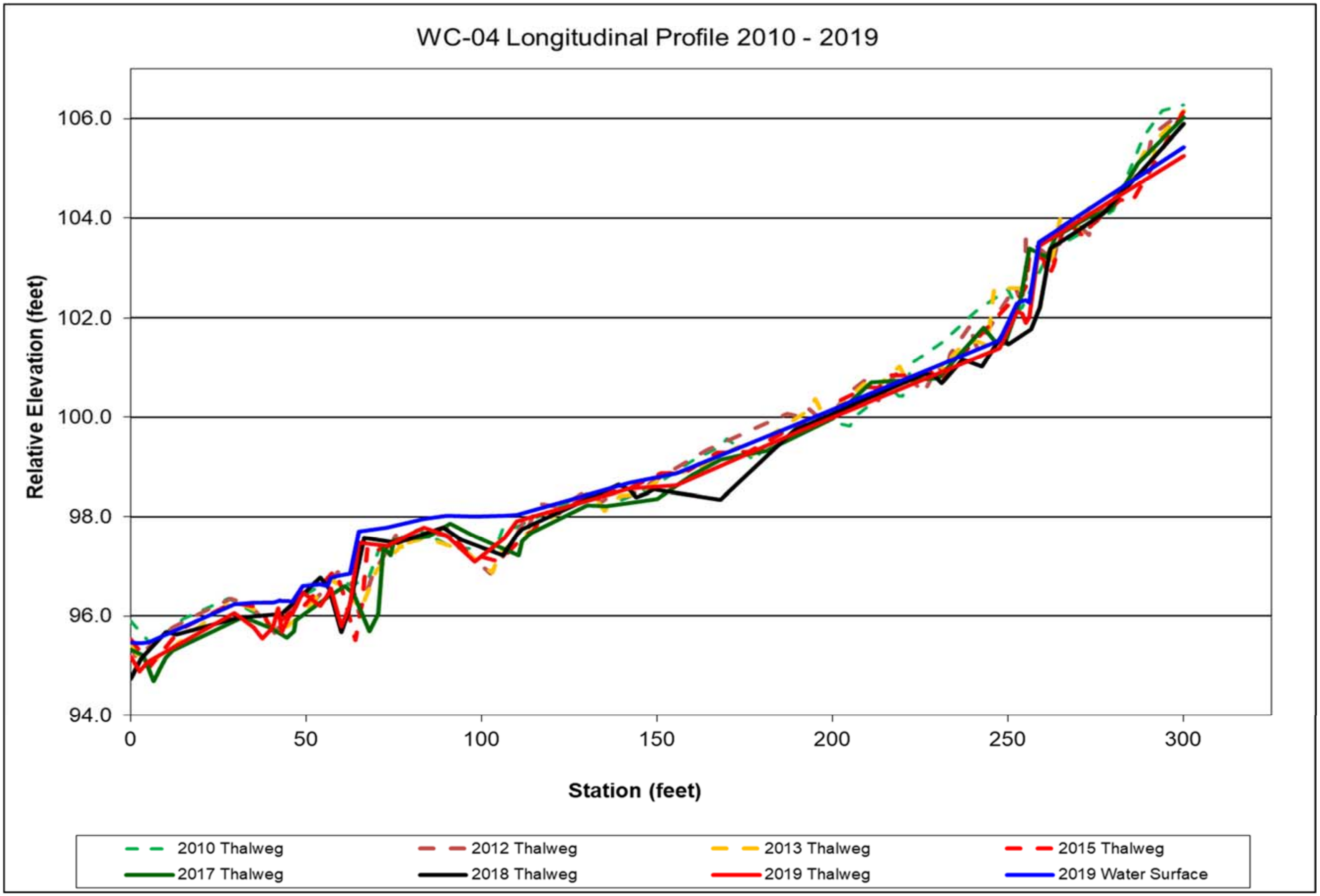

Figure C-6. WC-04 Longitudinal Profile (Pre- and Post-Restoration)

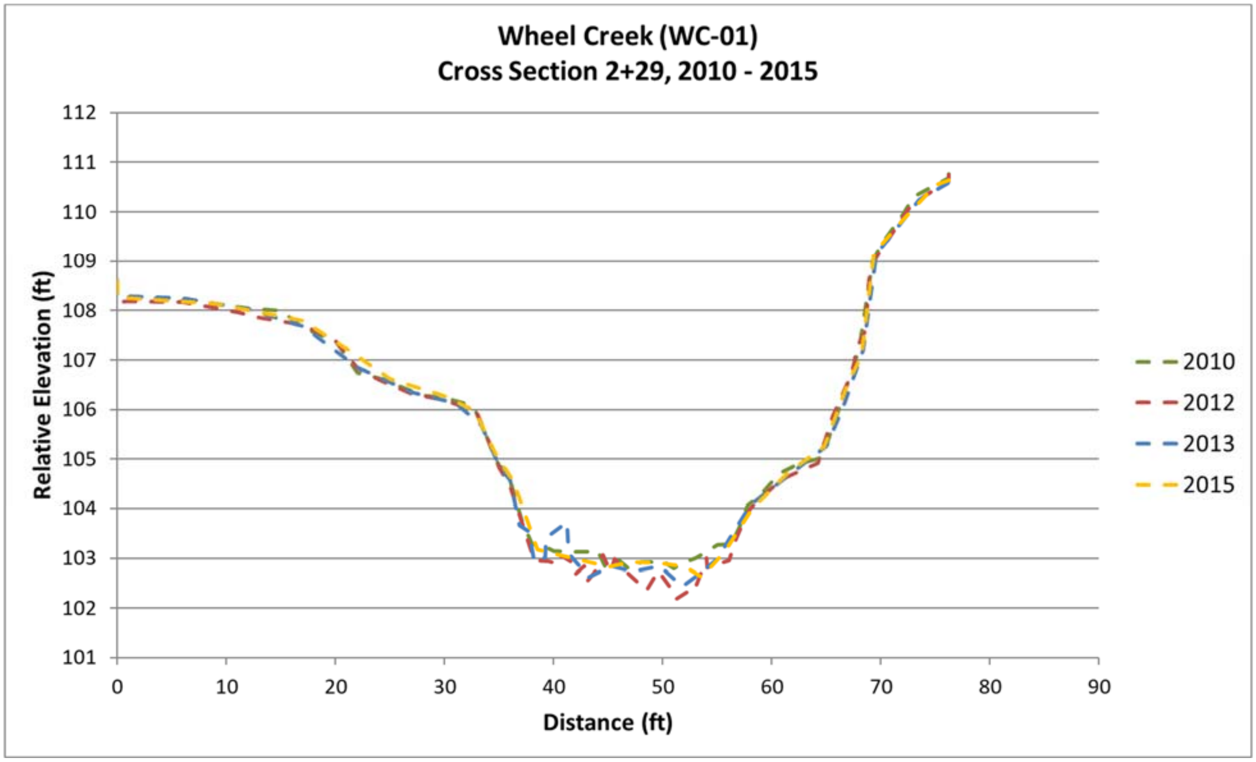

Figure C-7. WC01 Cross-section 1 (Pre-Restoration)

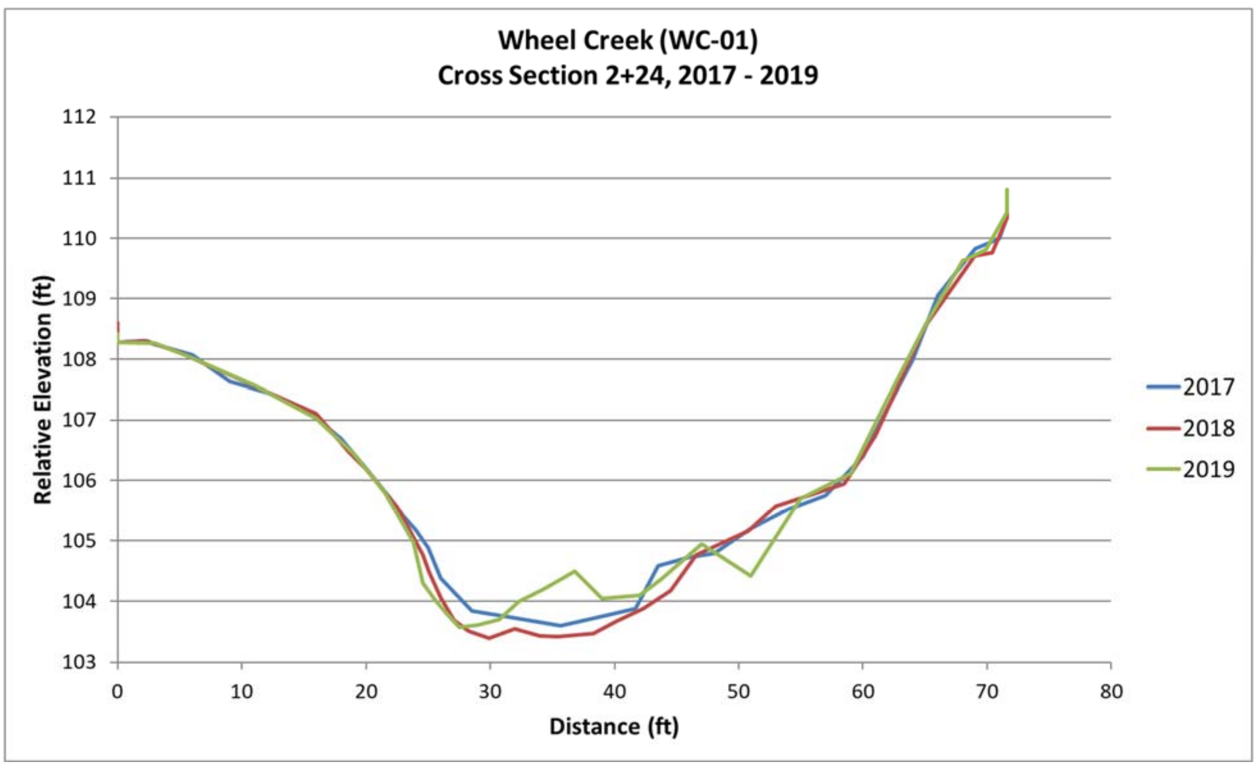

Figure C-8. WC01 Cross-section 1 (Post-Restoration)

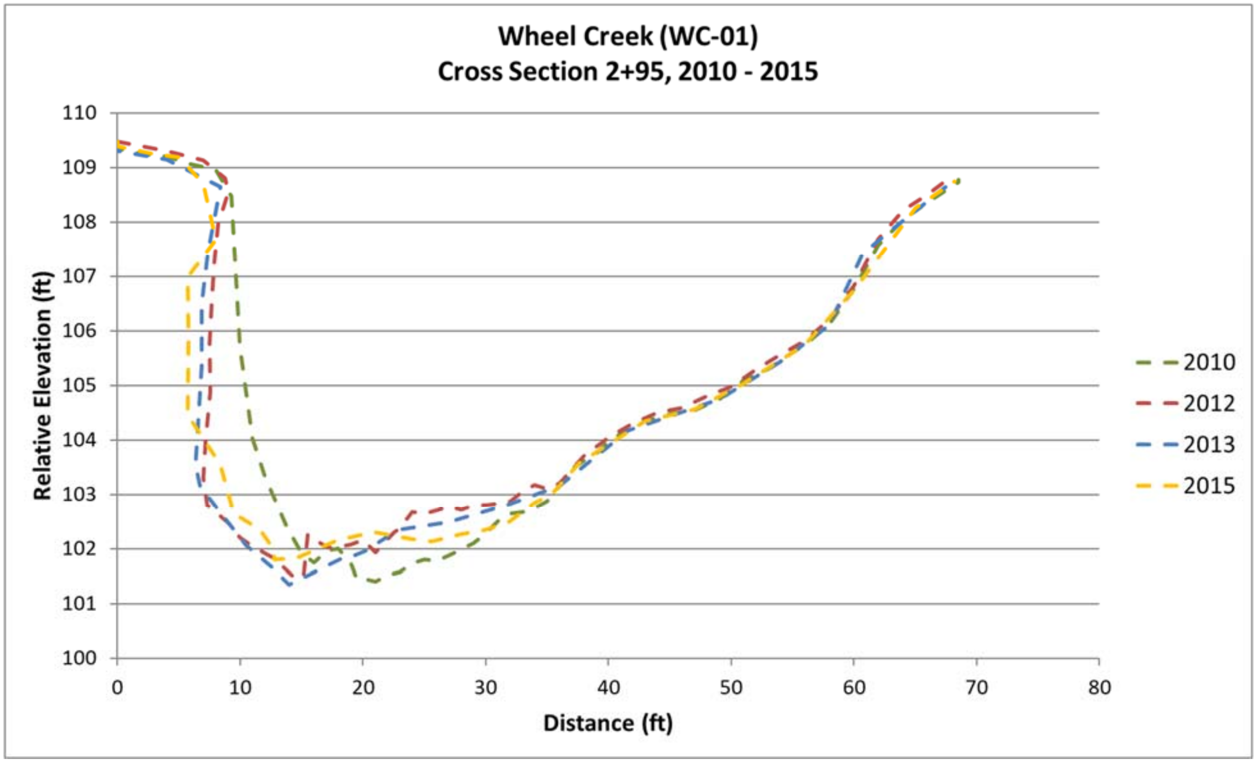

Figure C-9. WC01 Cross-section 2 (Pre-Restoration)

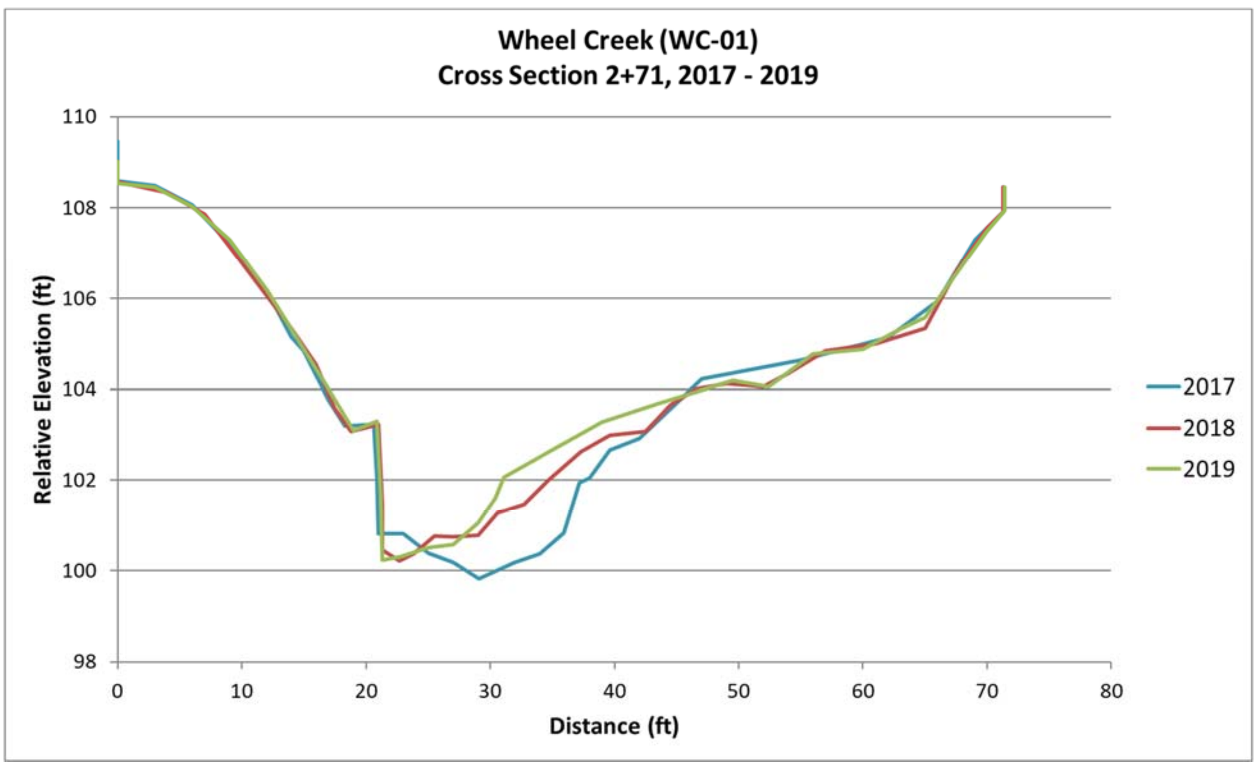

Figure C-10. WC01 Cross-section 2 (Post-Restoration)

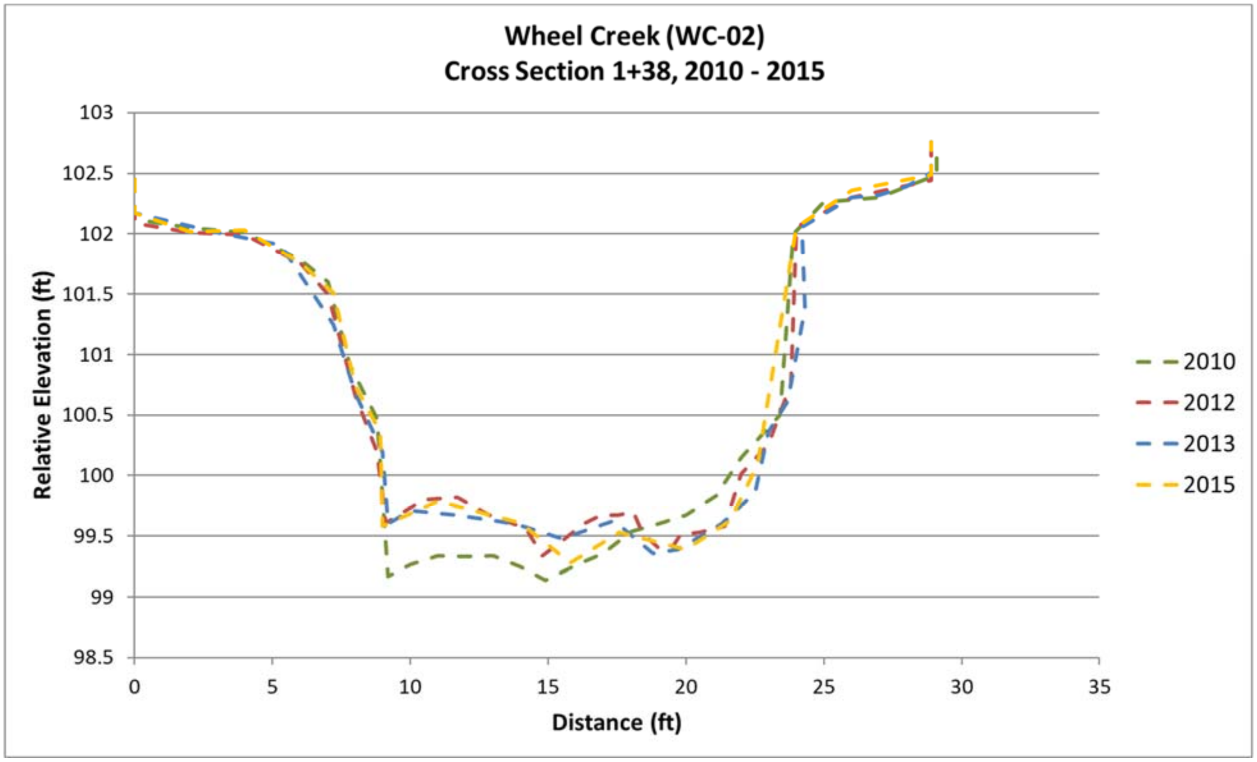

Figure C-11. WC02 Cross-section 1 (Pre-Restoration)

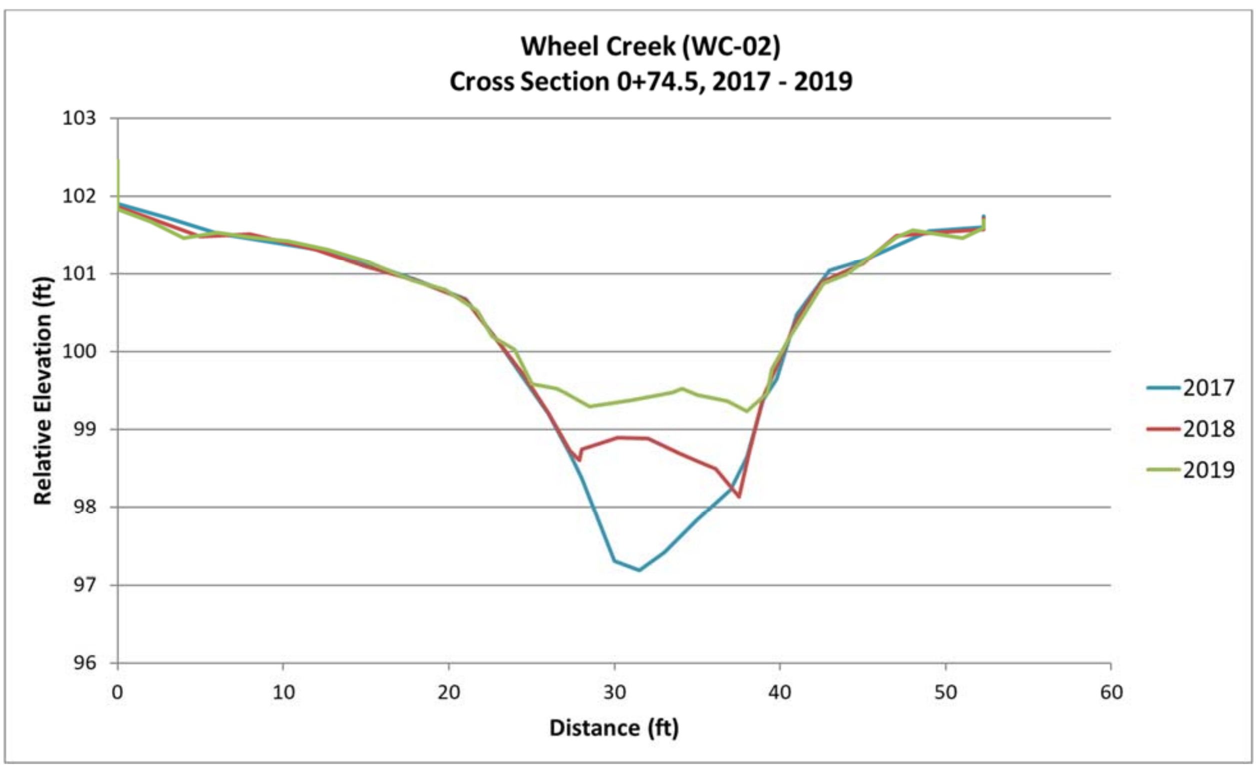

Figure C-12. WC02 Cross-section 1 (Post-Restoration)

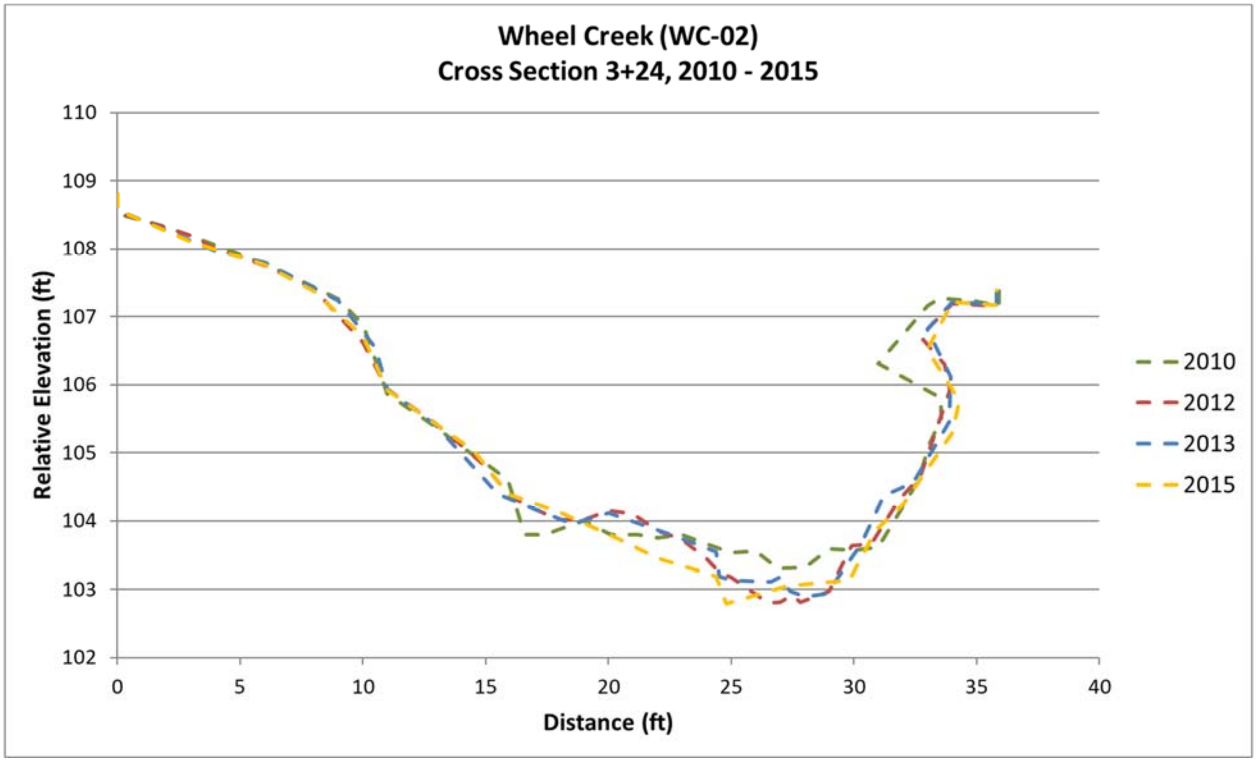

Figure C-13. WC02 Cross-section 2 (Pre-Restoration)

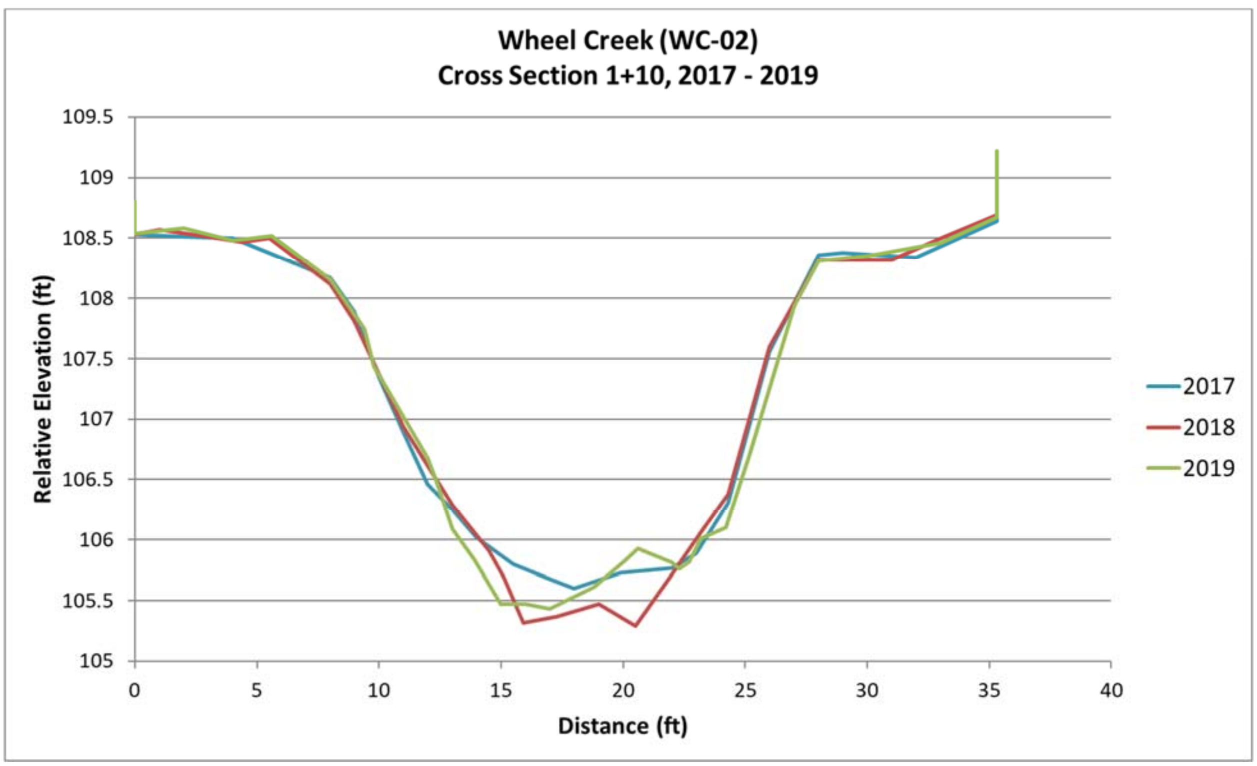

Figure C-14. WC02 Cross-section 2 (Post-Restoration)

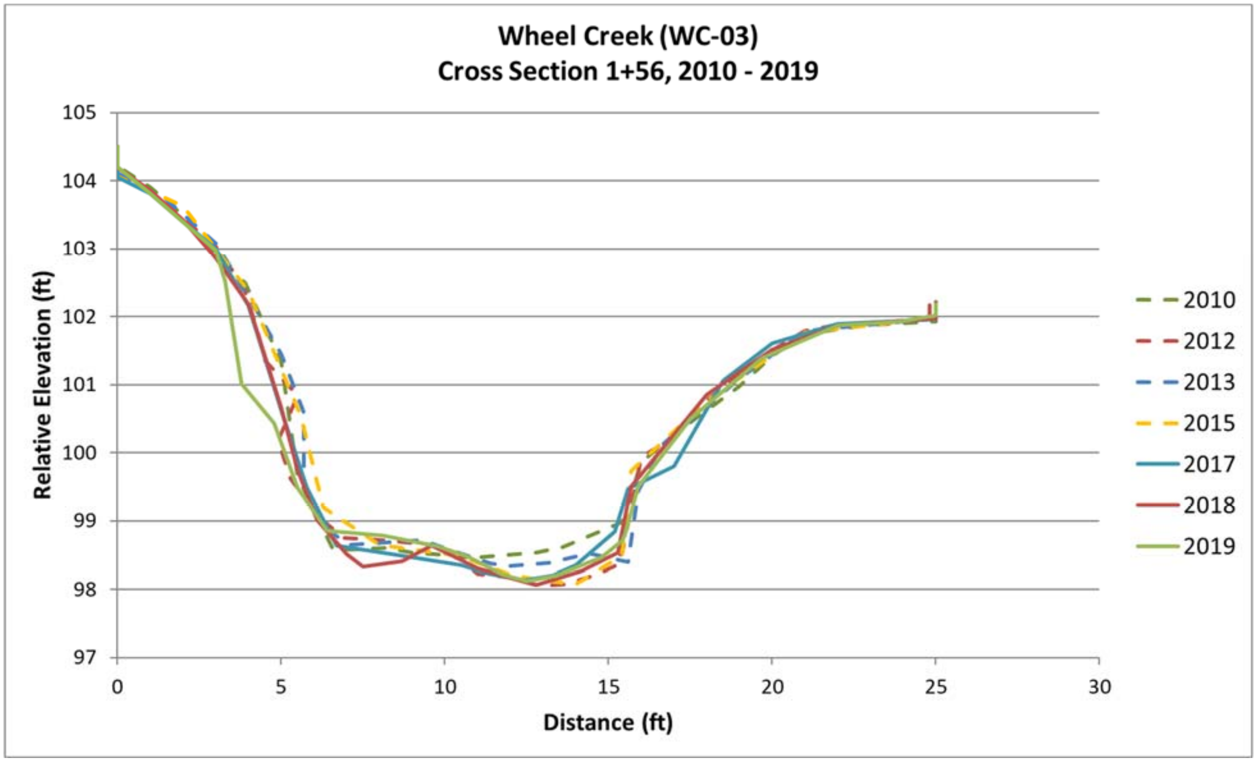

Figure C-15. WC03 Cross-section 1 (Pre- and Post-Restoration)

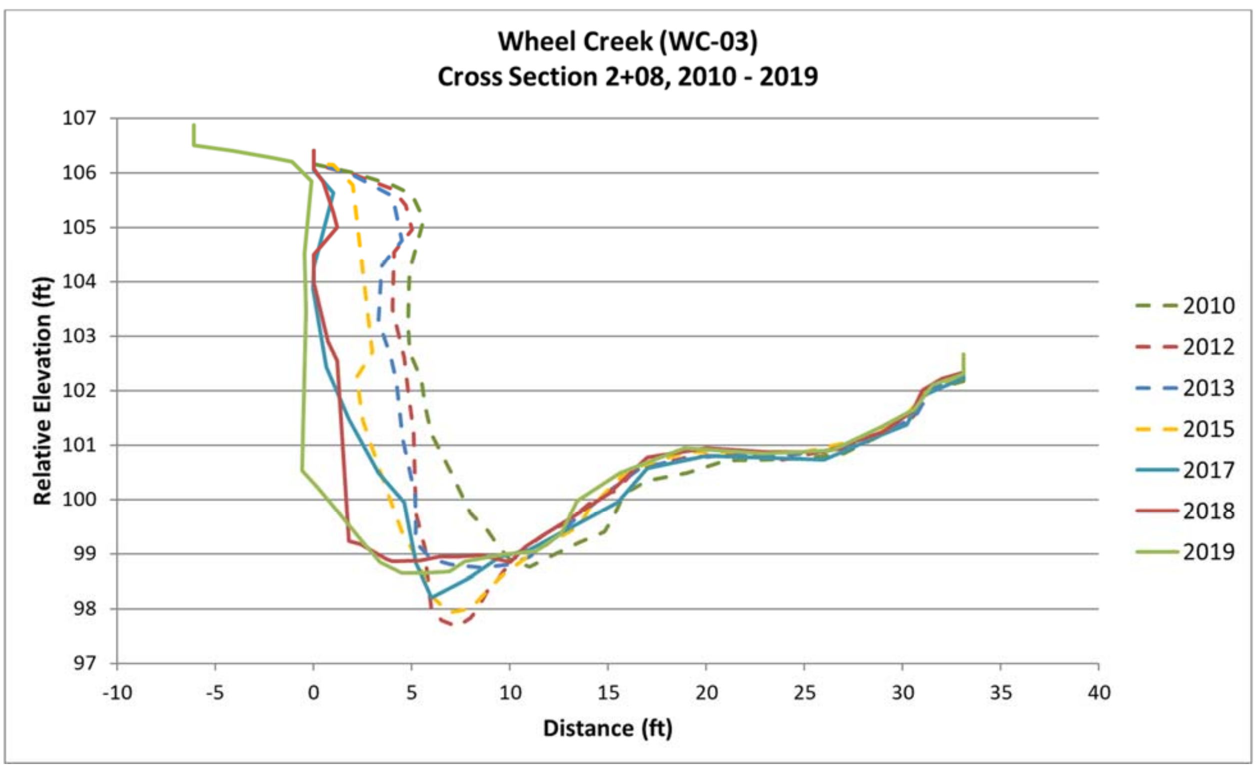

Figure C-16. WC03 Cross-section 2 (Pre- and Post-Restoration)

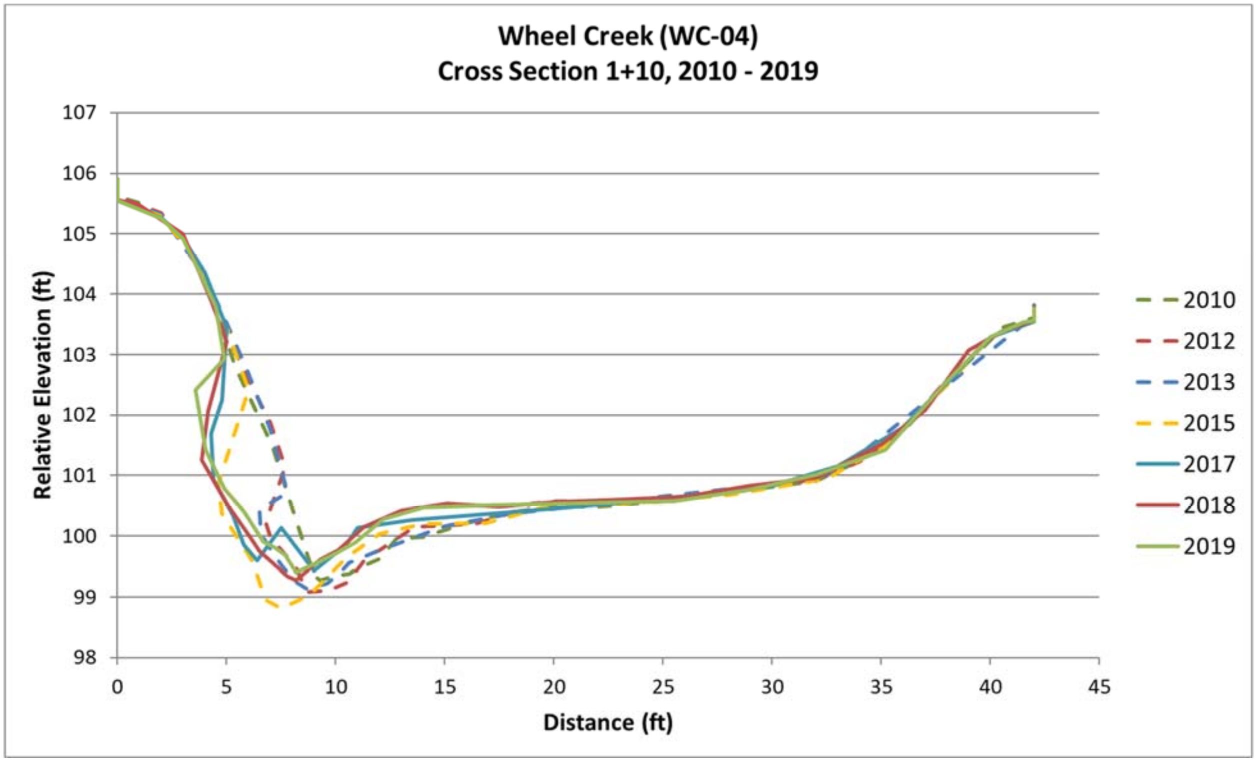

Figure C-17. WC04 Cross-section 1 (Pre- and Post-Restoration)

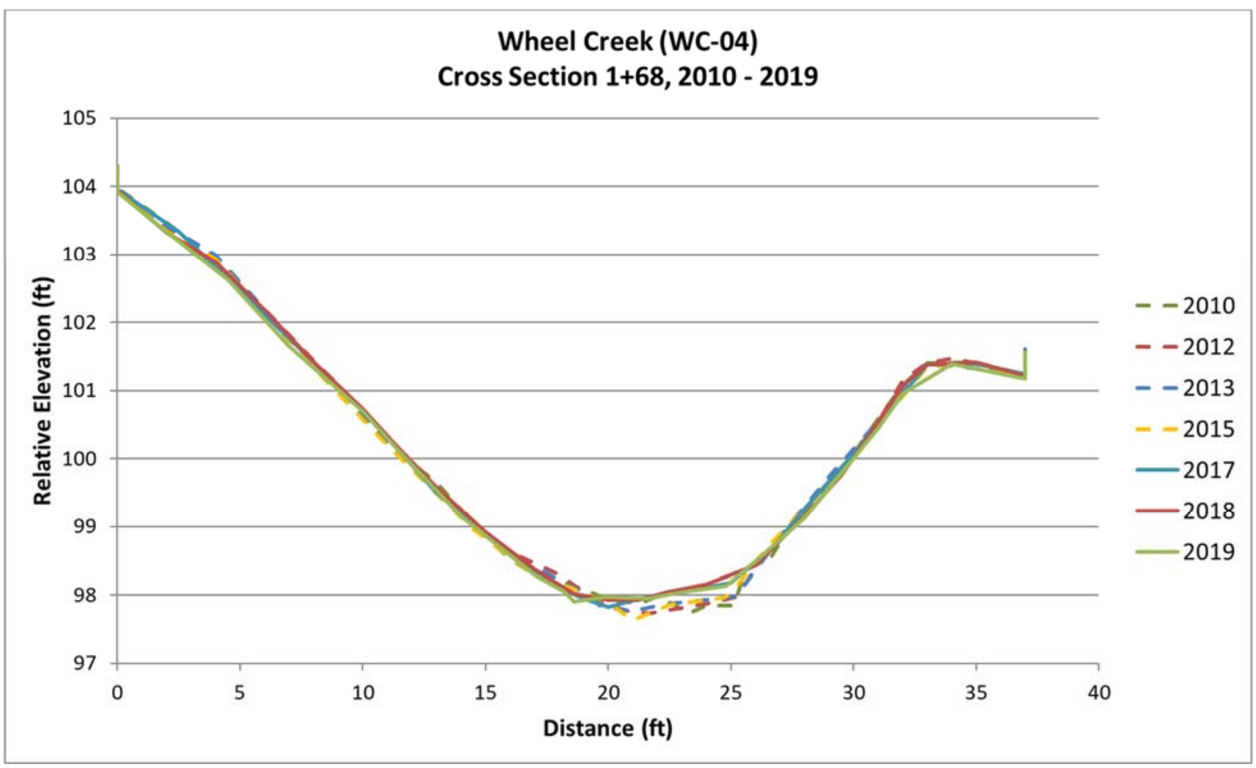

Figure C-18. WC04 Cross-section 2 (Pre- and Post-Restoration)

Table C-3. Particle Size Distribution Pre-Restoration Years 1 – 4, Post-Restoration Years 1 – 3

	Riffle Feature Surface			***Meander Feature Surface***			***Reachwide***		
Year	**Measure**	**Size (mm)**	**Size Class**	**Measure**	**Size (mm)**	**Size Class**	**Measure**	**Size (mm)**	**Size Class**
WC01*									
2010	D50	39	very coarse gravel	D50	38	very coarse gravel	D50	44	very coarse gravel
2012	D50	56	very coarse gravel	D50	40	very coarse gravel	D50	51	very coarse gravel
2013	D50	49	very coarse gravel	D50	37	very coarse gravel	D50	55	very coarse gravel
2015	D50	50	very coarse gravel	D50	55	very coarse gravel	D50	42	very coarse gravel
2017	*D50*	*52*	*very coarse gravel*	*D50*	*11*	*medium gravel*	*D50*	*25*	*coarse gravel*
2018	*D50*	*41*	*very coarse gravel*	*D50*	*32*	*very coarse gravel*	*D50*	*47*	*very coarse gravel*
2019	*D50*	*47*	*very coarse gravel*	*D50*	*12*	*medium gravel*	*D50*	*37*	*very coarse gravel*
2010	D84	120	medium cobble	D84	90	medium cobble	D84	140	large cobble
2012	D84	180	large cobble	D84	77	small cobble	D84	120	medium cobble
2013	D84	130	large cobble	D84	87	small cobble	D84	130	large cobble
2015	D84	160	large cobble	D84	110	medium cobble	D84	150	large cobble
2017	*D84*	*120*	*small cobble*	*D84*	*57*	*very coarse gravel*	*D84*	*90*	*small cobble*
2018	*D84*	*150*	*large cobble*	*D84*	*97*	*medium cobble*	*D84*	*160*	*large cobble*
2019	*D84*	*110*	*medium cobble*	*D84*	*51*	*very coarse gravel*	*D84*	*90*	*small cobble*
WC02*									
2010	D50	50	very coarse gravel	D50	45	very coarse gravel	D50	49	very coarse gravel
2012	D50	40	very coarse gravel	D50	33	very coarse gravel	D50	28	coarse gravel
2013	D50	51	very coarse gravel	D50	47	very coarse gravel	D50	40	coarse gravel
2015	D50	36	very coarse gravel	D50	26	very coarse gravel	D50	36	very coarse gravel
2017	*D50*	*26*	*coarse gravel*	*D50*	*4.3*	*very fine gravel*	*D50*	*16*	*medium gravel*
2018	*D50*	*41*	*very coarse gravel*	*D50*	*64*	*small cobble*	*D50*	*27*	*coarse gravel*
2019	*D50*	*51*	*very coarse gravel*	*D50*	*16*	*medium gravel*	*D50*	*22*	*coarse gravel*
2010	D84	98	medium cobble	D84	94	medium cobble	D84	100	medium cobble
2012	D84	80	small cobble	D84	69	small cobble	D84	80	small cobble
2013	D84	88	small cobble	D84	86	small cobble	D84	110	medium cobble
2015	D84	100	medium cobble	D84	100	medium cobble	D84	110	medium cobble
2017	*D84*	*85*	*very coarse gravel*	*D84*	*19*	*medium gravel*	*D84*	*62*	*very coarse gravel*
2018	*D84*	*120*	*medium cobble*	*D84*	*130*	*large cobble*	*D84*	*110*	*medium cobble*
2019	*D84*	*110*	*medium cobble*	*D84*	*64*	*small cobble*	*D84*	*76*	*small cobble*

Table C-3. (Continued)

	Riffle Feature Surface			*Meander Feature Surface*			*Reachwide*		
Year	**Measure**	**Size (mm)**	**Size Class**	**Measure**	**Size (mm)**	**Size Class**	**Measure**	**Size (mm)**	**Size Class**
WC03									
2010	D50	33	very coarse gravel	D50	8.7	medium gravel	D50	28	coarse gravel
2012	D50	27	coarse gravel	D50	15	medium gravel	D50	23	coarse gravel
2013	D50	27	coarse gravel	D50	29	coarse gravel	D50	35	very coarse gravel
2015	D50	36	very coarse gravel	D50	7.2	fine gravel	D50	26	coarse gravel
2017	*D50*	*26*	*coarse gravel*	*D50*	*17*	*medium gravel*	*D50*	*16*	*medium gravel*
2018	*D50*	*26*	*coarse gravel*	*D50*	*14*	*medium gravel*	*D50*	*22*	*coarse gravel*
2019	*D50*	*45*	*very coarse gravel*	*D50*	*23*	*coarse gravel*	*D50*	*22*	*coarse gravel*
2010	D84	74	small cobble	D84	72	small cobble	D84	75	small cobble
2012	D84	59	very coarse gravel	D84	43	very coarse gravel	D84	72	small cobble
2013	D84	68	small cobble	D84	59	very coarse gravel	D84	130	large cobble
2015	D84	85	small cobble	D84	30	coarse gravel	D84	69	small cobble
2017	*D84*	*59*	*very coarse gravel*	*D84*	*61*	*very coarse gravel*	*D84*	*50*	*very coarse gravel*
2018	*D84*	*69*	*small cobble*	*D84*	*50*	*very coarse gravel*	*D84*	*51*	*very coarse gravel*
2019	*D84*	*88*	*small cobble*	*D84*	*70*	*small cobble*	*D84*	*80*	*small cobble*
WC04									
2010	D50	30	coarse gravel	D50	18	coarse gravel	D50	22	coarse gravel
2012	D50	36	very coarse gravel	D50	15	medium gravel	D50	24	coarse gravel
2013	D50	33	very coarse gravel	D50	1.5	very coarse sand	D50	36	very coarse gravel
2015	D50	35	very coarse gravel	D50	8.3	medium gravel	D50	28	coarse gravel
2017	*D50*	*43*	*coarse gravel*	*D50*	*12*	*medium gravel*	*D50*	*21*	*medium gravel*
2018	*D50*	*33*	*very coarse gravel*	*D50*	*1.9*	*very coarse sand*	*D50*	*17*	*coarse gravel*
2019	*D50*	*27*	*coarse gravel*	*D50*	*1.2*	*very coarse sand*	*D50*	*23*	*coarse gravel*
2010	D84	80	small cobble	D84	87	small cobble	D84	71	small cobble
2012	D84	64	small cobble	D84	70	small cobble	D84	76	small cobble
2013	D84	57	very coarse gravel	D84	64	small cobble	D84	79	small cobble
2015	D84	66	small cobble	D84	24	coarse gravel	D84	72	small cobble
2017	*D84*	*99*	*small cobble*	*D84*	*26*	*coarse gravel*	*D84*	*68*	*very coarse gravel*
2018	*D84*	*70*	*small cobble*	*D84*	*32*	*very coarse gravel*	*D84*	*47*	*very coarse gravel*
2019	*D84*	*80*	*small cobble*	*D84*	*29*	*coarse gravel*	*D84*	*81*	*small cobble*

*Profiles and cross-sections re-established during Post-Restoration Year 1 (2017)

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